NASA-TFAWS Short Course
ISS Payload Thermal Environments

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Purpose/Scope

Laurie Carrillo

Purpose/Scope

- This course will help an external payload developer understand the potential thermal environments associated with the various mission phases from launch to installation on ISS

- The course will also address the following topics:
  - Thermal analysis resources available to a payload developer
  - The need for payload/ISS integrated thermal analysis
  - Thermal analysis approaches used by ISS PTCS
  - Overview of the ISS Reduced Fidelity Model
  - Lessons learned for thermal model integration

ISS Fun Facts

International Space Station

- Contributions from 16 Nations: US, Russia, Canada, Japan, Brazil, Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom
- First elements launched – 11/20/1998 (Zarya Module), 12/4/1998 (Unity Node 1 Module)
- First permanent crew arrived (three-person) – 11/2/2000
- US-Segment designated as a National Laboratory by the 2005 NASA Authorization Act
- US-Segment completed - full International six-person crew size achieved -2009
- All external logistics/payload stowage sites installed - 2011
- Currently, an international crew of six; more than 200 people from 15 countries have visited

1. Introduction

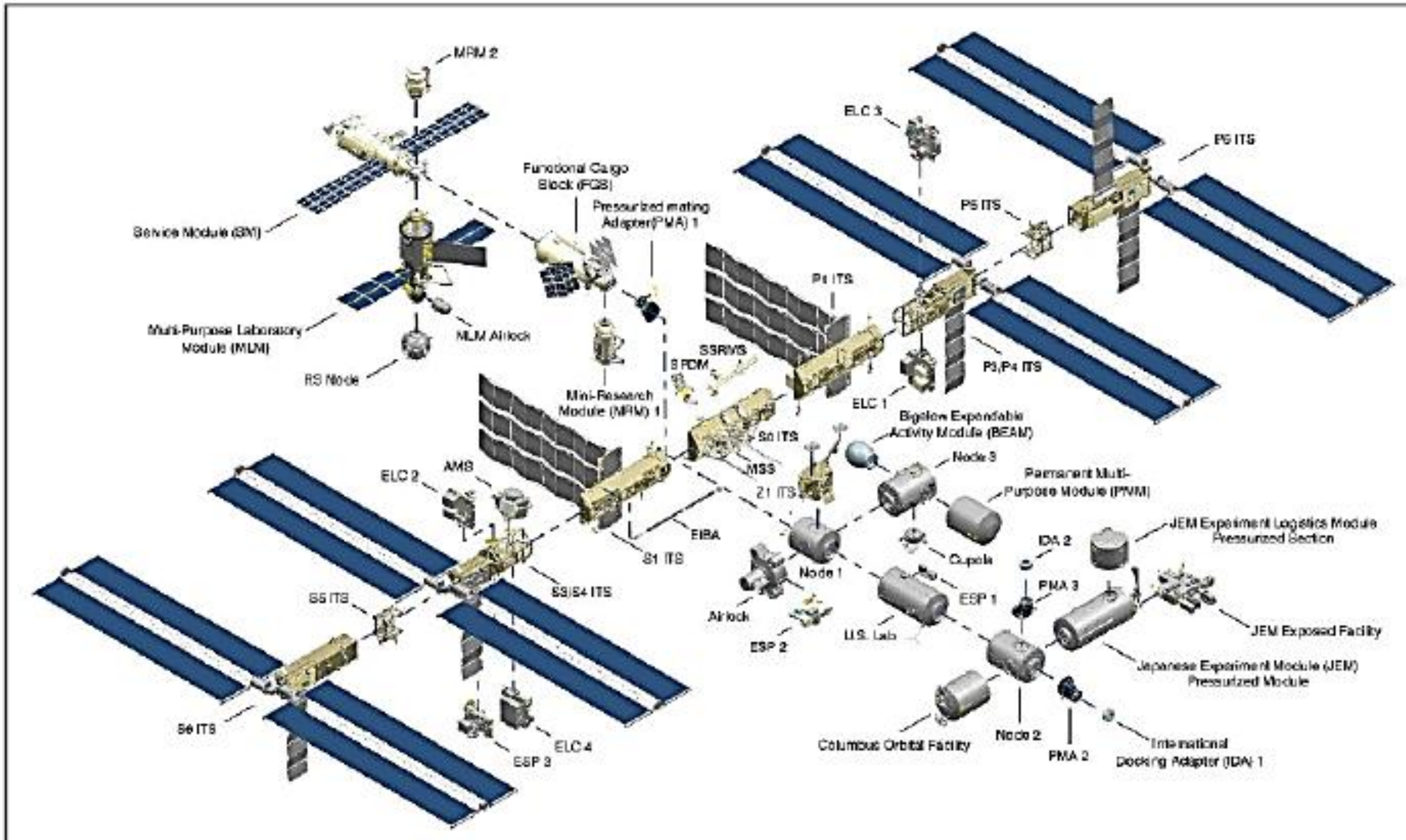
David Farner

Agenda

1. Introduction
2. Mission Phases
3. ISS Parameters Impacting Thermal Environments
4. Integrated Thermal Analysis
5. Representative Environments
6. ISS Reduced Fidelity Model
7. Integration Lesson Learned
8. Conclusions
9. Q & A

Exterior View of the International Space Station (ISS)

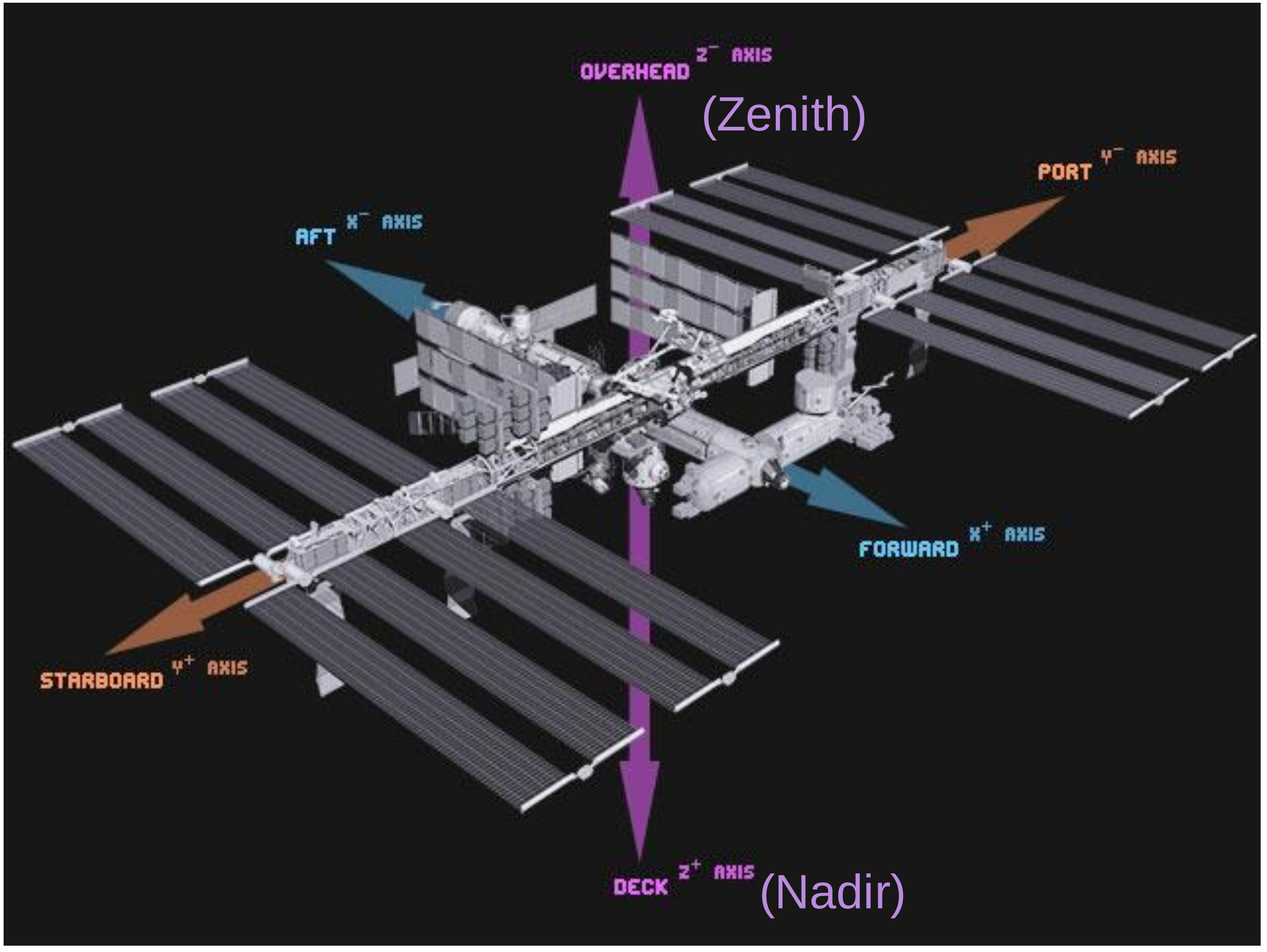
ISS Components



Note – ISS configuration shown is for 6R (not all components may be on-orbit)

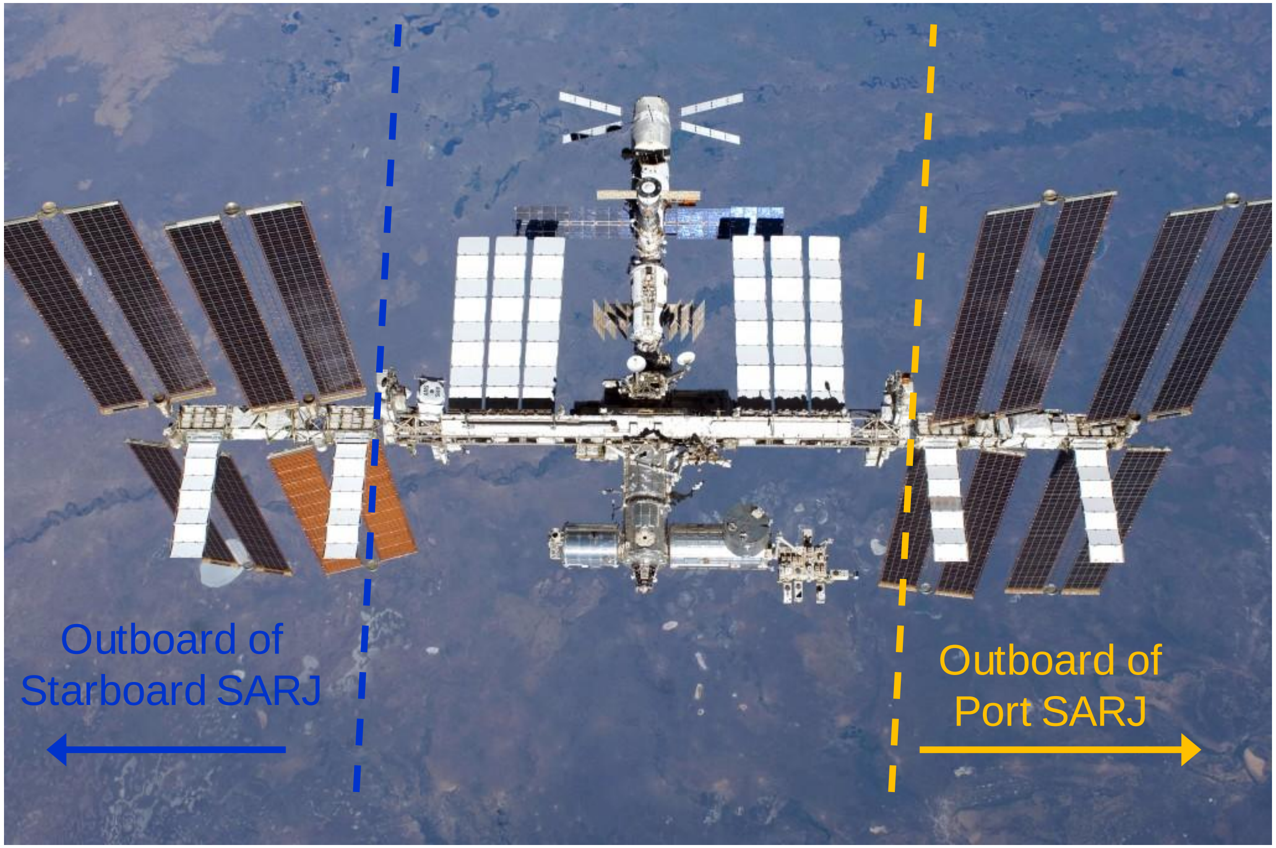
Introduction

ISS Coordinate System



Introduction

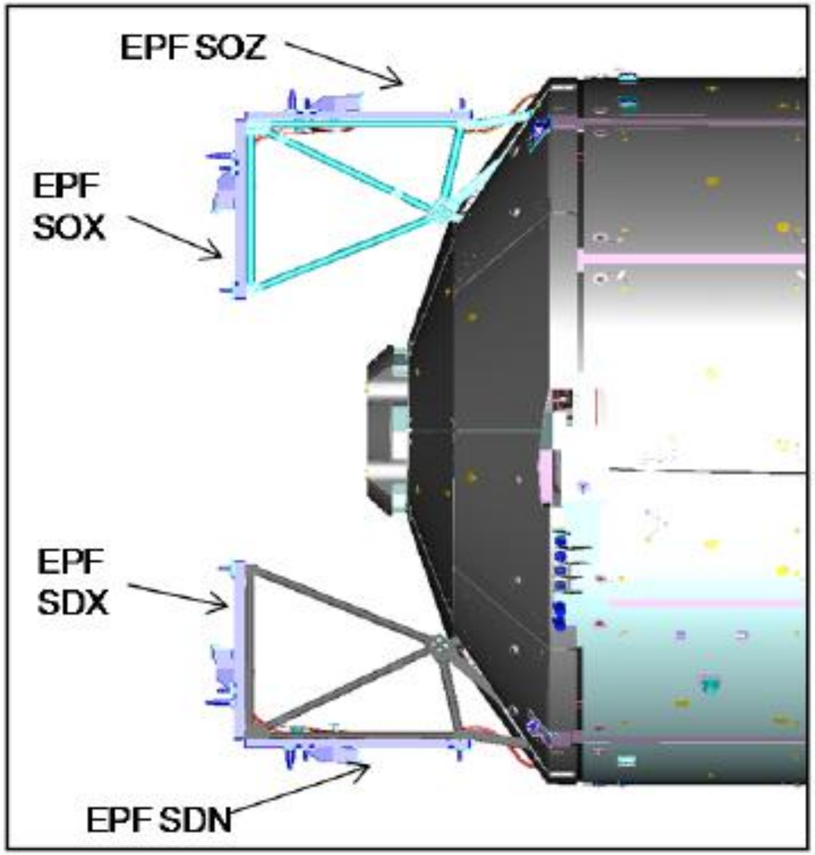
Extravehicular Activity (EVA) Impacts on ISS Attitudes



- EVAs inboard of the Solar Alpha Rotary Joints (SARJs) are planned in +/- XVV
- EVAs outboard of the SARJs are planned in +/- YVV

Introduction

Columbus Attach Sites (4 Total)

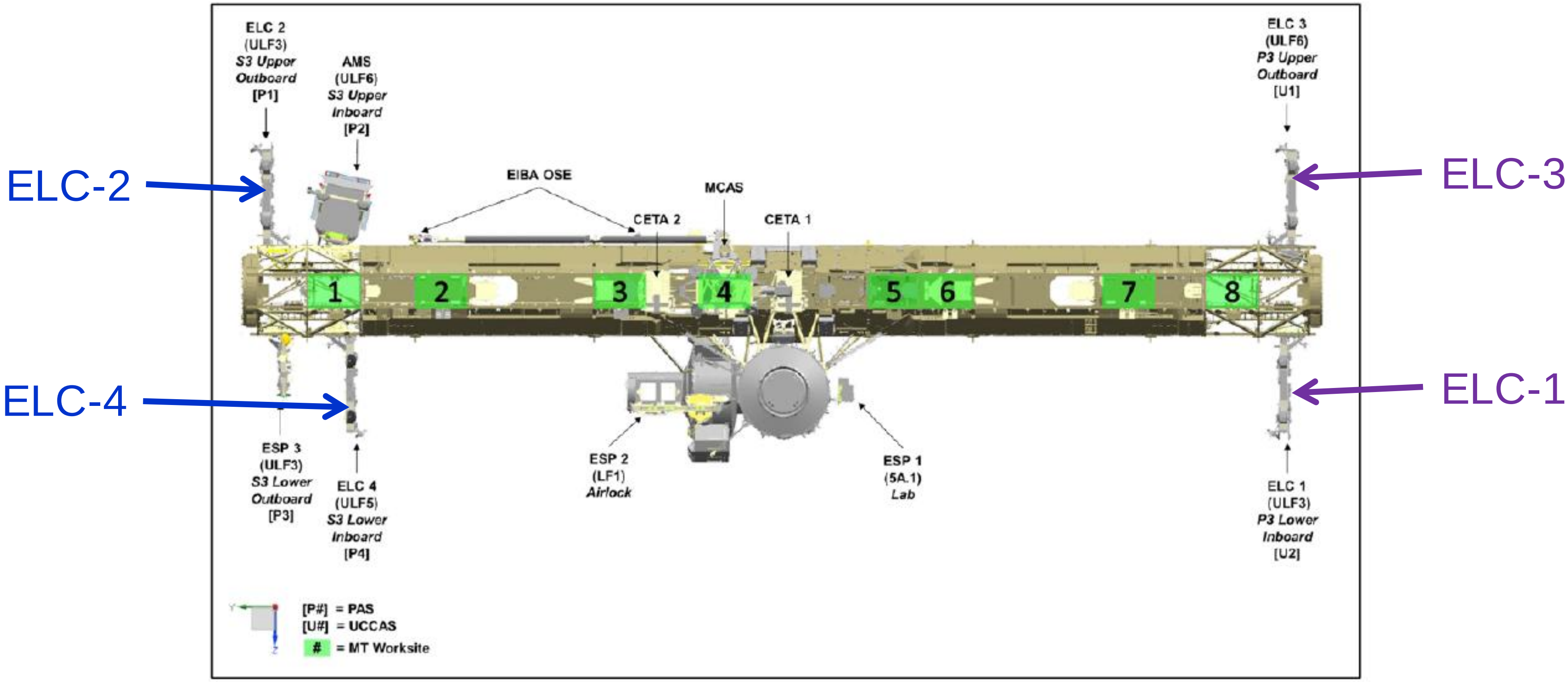


Note: View is from ISS +X looking Aft (–X direction)

- The Flight Releasable Attachment Mechanism (FRAM) is used to attach an external payload to a Columbus site as well as providing a power/data interface to the payload

Introduction

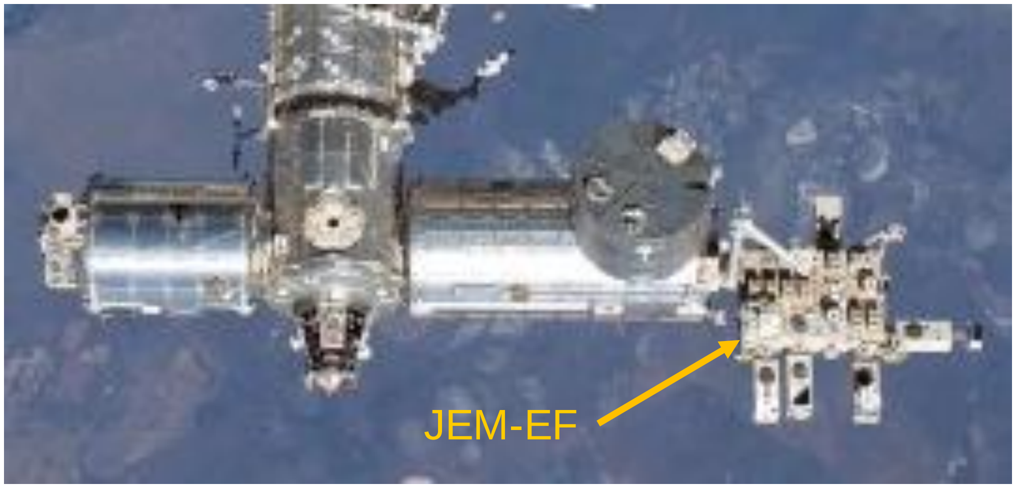
ExPRESS Logistics Carrier (ELC) Locations



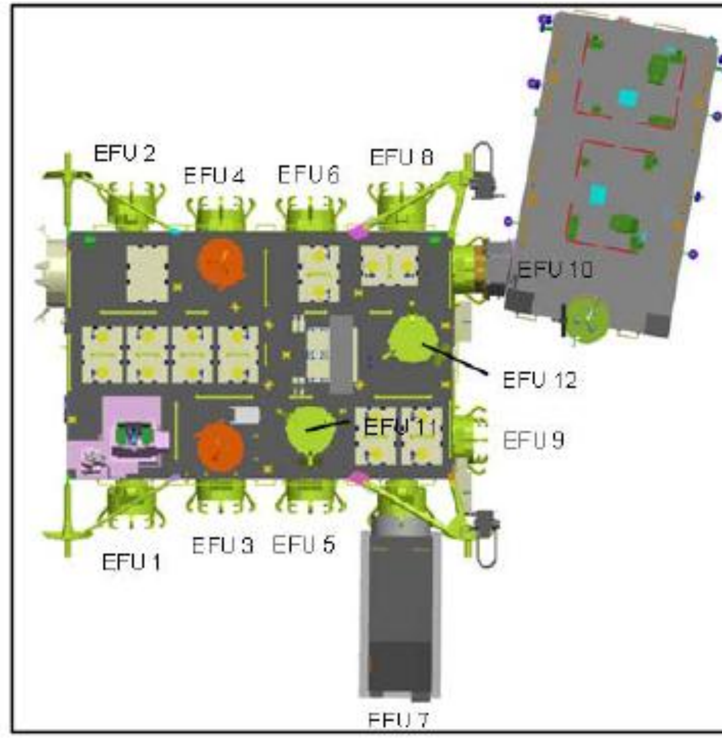
- The four ELC locations serve as storage locations for EVA replaceable ISS spares
  - There are two ELC locations (ELC-4 & ELC-2) on the starboard side of ISS and two ELC locations (ELC-1 and ELC-3) on the port side of ISS
  - Each ELC has inboard and outboard facing attach sites
- The payloads are attached to an ELC location using the FRAM interface

Introduction

Japanese Experimental Module Exposed Facility (JEM-EF)



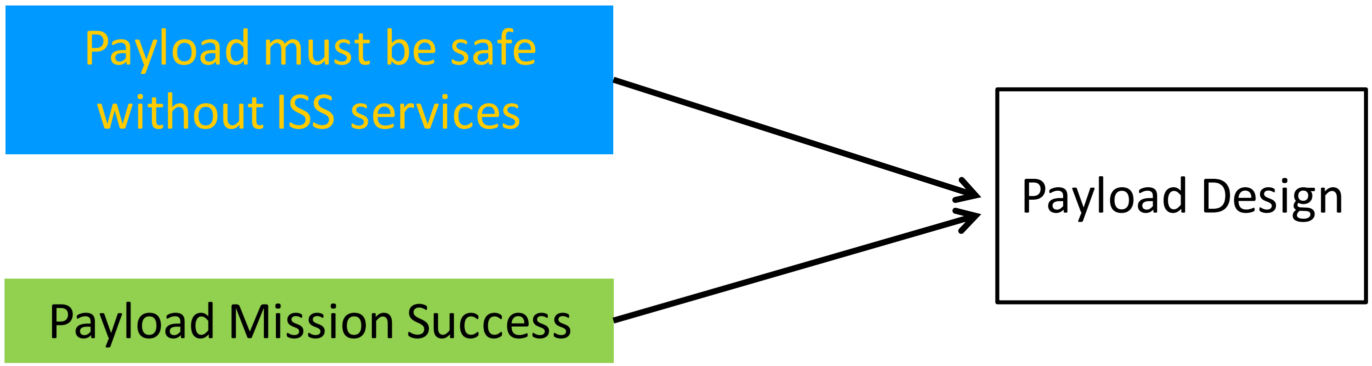
The JEM-EF also has EVA replaceable spares on it



Note: View is from ISS Zenith looking Nadir (-Z direction)

- There are multiple attach sites for external payloads with the Japan Aerospace Exploration Agency (JAXA) supplied JEM-EF interface known as the Payload Interface Unit (PIU)
  - Payloads at this site are actively cooled and most of the payload exterior is covered with Multilayer Insulation (MLI)

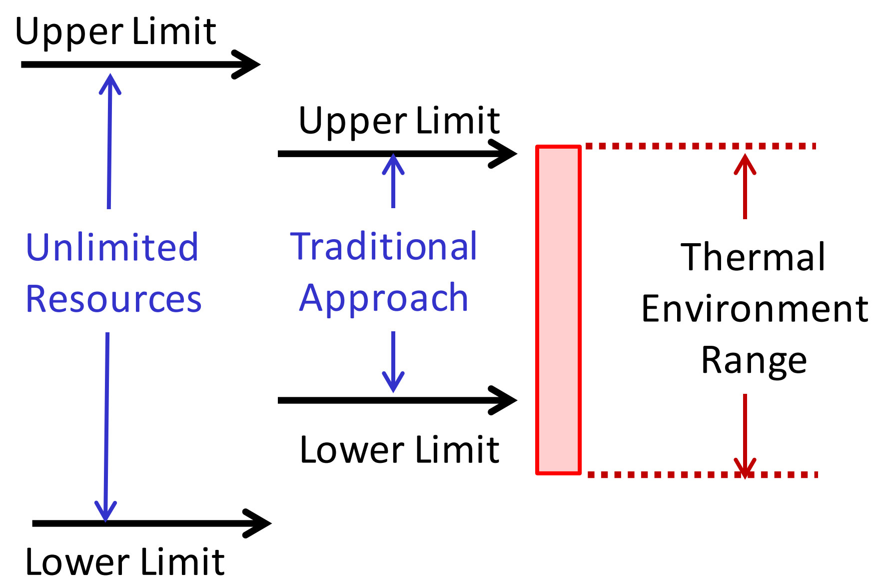
Introduction



- For "Payload must be safe without ISS services":
  - Payload design must meet these requirements
  - Some requirements such as EVA touch temperature need payload to examine "integrated configuration" which may include flight support items that remain on the payload after ISS installation (example grapple fixtures, FRAM)
  - ISS has initiated "Revolutionize ISS for Science and Exploration (RISE)" to review/streamline these requirements
- The payload is responsible for ensuring design meets the requirements tied to mission success
  - ISS program will provide support/information about how ISS operations can impact a payload

Introduction

Passive Thermal Design Approach



- For the “Traditional” approach, the thermal environment range is based on the worst case cold/hot parameters:
  - Design may use surface coatings or component selection to ensure payload upper limit is compatible with the expected environment
  - Use of heaters or component selection to protect the payload’s lower limit

2. Mission Phases

David Farner

Payload Mission Phases

Key Mission Phases

- Phase 1 consists of ground transport up to launch
  - Component selection or hardware controls are used to ensure payload remains within temperature limits during this phase
- Phase 2 consists of launch vehicle solo flight
  - Power available to a payload depends on both internal and external payload manifest
  - Solo flight environment may drive heater design and thermal survival in general
    - Solo flight environments are not being addressed in this presentation
  - Currently only SpaceX Dragon and JAXA HTV can carry external payloads

Key Mission Phases

- Phase 3 consists of launch vehicle berthed to ISS
  - Environment/heater design dictates payload initial temperature before starting unpowered transfer
  - Nadir ports tend to produce payload environment more benign than solo flight
  - Payload should evaluate if thermal recovery time from solo flight is needed
  - For payloads with unpowered transfer capability less than 6 hours, may want additional heaters to raise payload initial temperature (power available for additional heaters limited by launch vehicle and may require payload be removed last from launch vehicle)

Payload Mission Phases

Key Mission Phases (Continued)

- Phase 4 consists of payload extraction from launch vehicle and installation on ISS
  - Payload will undergo some unpowered time period during this phase
    - Requirement is 6 hours for ELC installation and 7 hours for JEM-EF installation
  - The required unpowered time period can be an issue in cold environments
  - For a payload going to nadir installed ELC (ELC-1 or ELC-4), cold design environment may occur for this phase at a point along the robotic arm trajectory
  - Payload may need to evaluate heater design at intermediate ISS locations besides launch vehicle and ISS install location
  - Unpowered cold capability highly dependent on lower limits of payload components
    - Typical ISS hardware spares have lower limit of -40° C
  - Deployment from JEM Airlock is similar to this phase, and also requires evaluation of JEM Airlock operation requirements

Key Mission Phases (Continued)

- Phase 5 begins when payload receives ISS provided services (power, data, etc.)
  - Both planned and unplanned power loss may occur during this phase with a 6 hour unpowered requirement for ELC payloads
- Phase 6 consists of payload removal/disposal
  - Design impacts could occur if "safe without ISS services" requirement not sufficient for this phase

Payload Unpowered Capability

- Key factors in a payload's unpowered capability: geometry, optics, component temperature limits, and the thermal environment
  - Most ISS hardware has lower limit ~ -40° C
  - Not unusual for the average thermal environment for an orbital time interval of 1.5 hours at many ISS locations to be between -30° C to -50° C (depending on payload exterior optics)
    - A shaded location which receives little solar flux, the environment can drop down to -60° C
    - Additional details about potential thermal environments will be presented in section 5
- Robotic operations needed for launch vehicle removal to ISS installation highly dependent on a payload's unpowered capability
  - Requires coordination with ISS robotics team to understand potential robotic trajectories
  - Adding an additional robotic interface to power a payload's heater system may reduce unpowered time, but does not eliminate it
    - Payload developer should coordinate with ISS robotics team about design considerations such as power allotment
  - The payload's heater design should evaluate "thermal recovery" which may be needed along the robotics trajectory

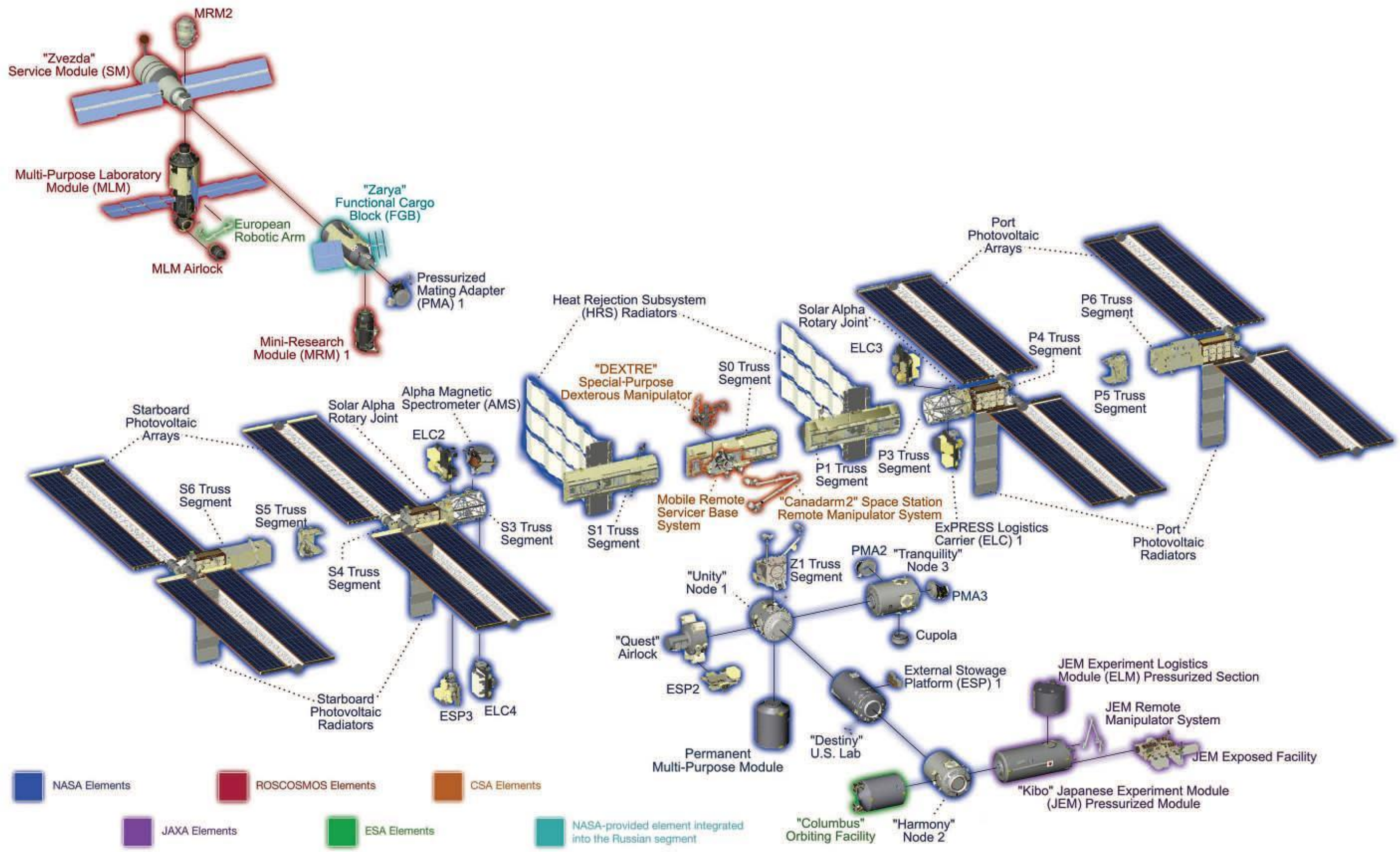
3. ISS Parameters Impacting Thermal Environments

Laurie Carrillo

Overview

- Payload's on-orbit thermal environment
  - Produces the payload's external heating rate
  - Drives the payload design
  - Varies as the International Space Station (ISS) parameters change
- This section will focus on ISS key parameters:
  - Orbital Parameters
  - Optical Properties
  - Solar Beta Angle
  - Flight Orientation and Attitude
  - Rotating Surfaces
  - Plume Heating
- Design Verification Summary

International Space Station Exploded View



ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Orbital Parameters

- Space environment heating sources
  - Solar Flux
    - Radiative heat received from the sun (W/m^2 or $Btu/hr\text{-}ft^2$)
    - Varies over time due to Earth's orbit about the sun
    - Range: 1321 W/m^2 (418 $Btu/hr\text{-}ft^2$) to1423 W/m^2 (451 $Btu/hr\text{-}ft^2$)
  - Albedo
    - Solar heat reflected off the Earth onto the spacecraft
  - Outgoing Long-Wave Radiation (OLR)
    - Earth's radiated heat received
    - Infrared region
  - Orbital heating rate varies with time over the orbit
- Altitude
  - Distance from the surface of the Earth to the spacecraft
    - ISS design range is 150 nmi (278 km) to 270 nmi (500 km)
  - Determines the orbital period or the time to complete a revolution around the Earth
    - Nominal orbit is 1.5 hours
  - Atmospheric drag causes the ISS to lose altitude
  - Periodic reboosts restore the ISS altitude to between 210 nmi (389 km) to 220 nmi (407 km)
    - Historically this altitude range does not significantly impact the thermal environment

ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Optical Properties

- Spectrum Region
  - Solar is emitted in the 0.25 to 2.5 μm band
    - Absorptivity (α)
    - Transmissivity (τ)
    - Reflectivity (ρ)
  - Infrared (IR) every thing outside of the solar band
    - Emissivity (ε)
    - Transmissivity (τ)
    - Reflectivity (ρ)

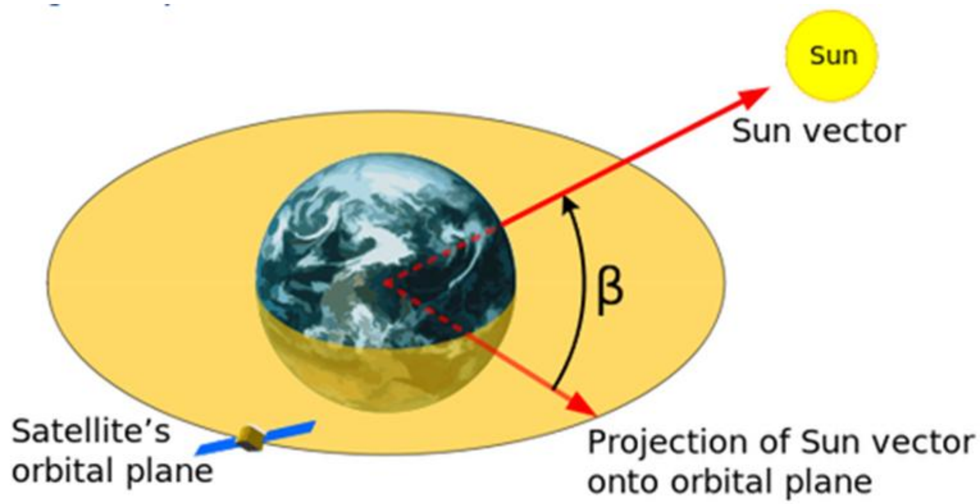
- Beginning of Life (BOL) properties
  - Properties at the mission start

- End of Life (EOL) properties
  - Surface degradation: atomic oxygen, contamination, extreme vacuum, ultra-violet radiation and charged particles
  - Typically Increase Solar α
  - Typically Little impact to IR ε

ISS Parameters Impacting Thermal Environments

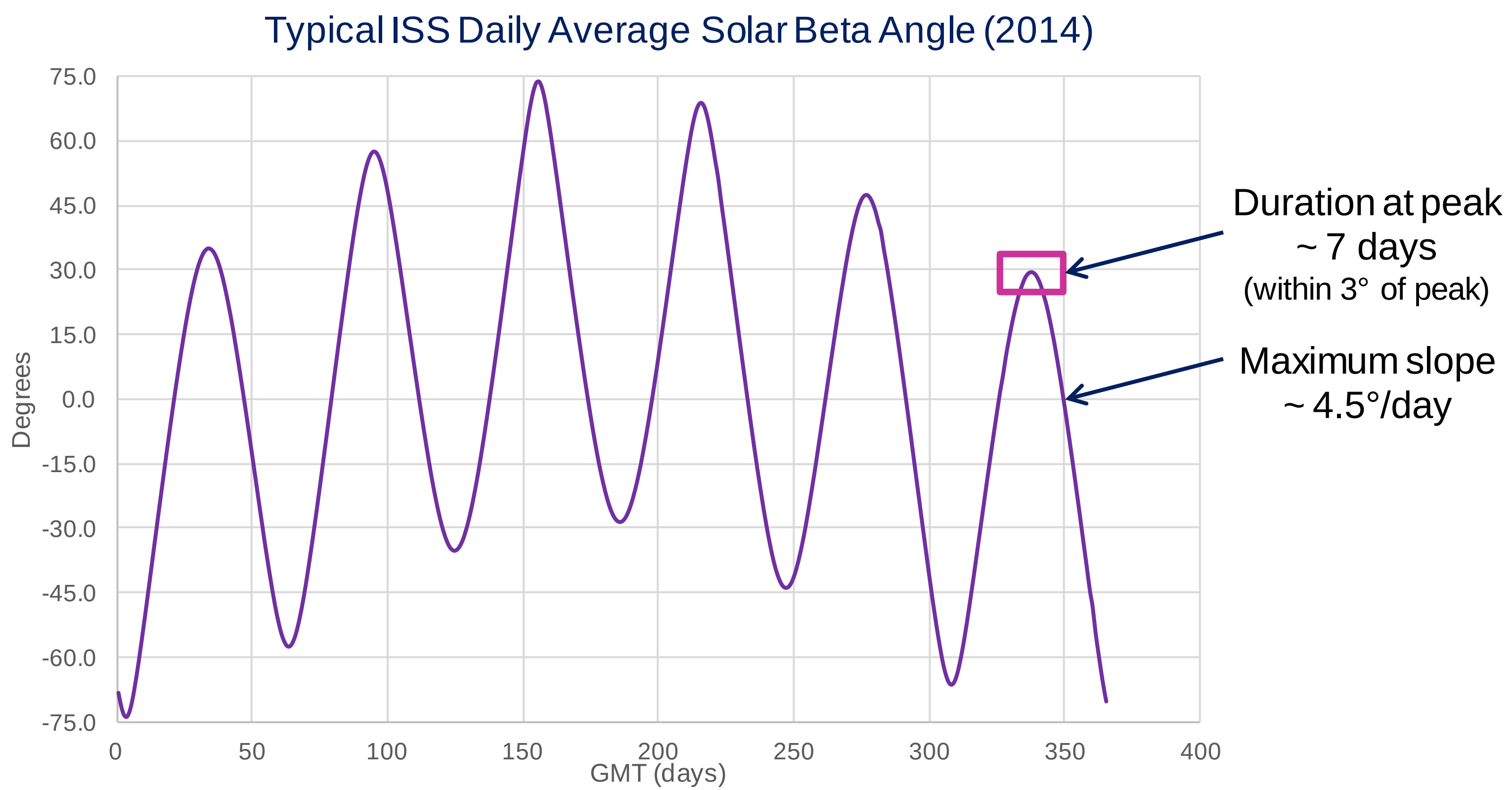
ISS Environmental Drivers: Solar Beta Angle

- Solar beta angle is defined as the angle between the orbital plane and a line drawn from the Sun to Earth and is shown as β in the figure
  - The angle varies throughout the year due to the ISS orbit's precession (caused by non-uniformity of the Earth's gravitational field, etc.) and the Earth's rotation about the sun
- Dictates the amount of time spent in the sun vs. eclipse
- High beta results in short or no eclipse time/ majority of time spent in sunlight
- Low beta results in longer eclipse times/short amount of time in sunlight



ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Solar Beta Angle

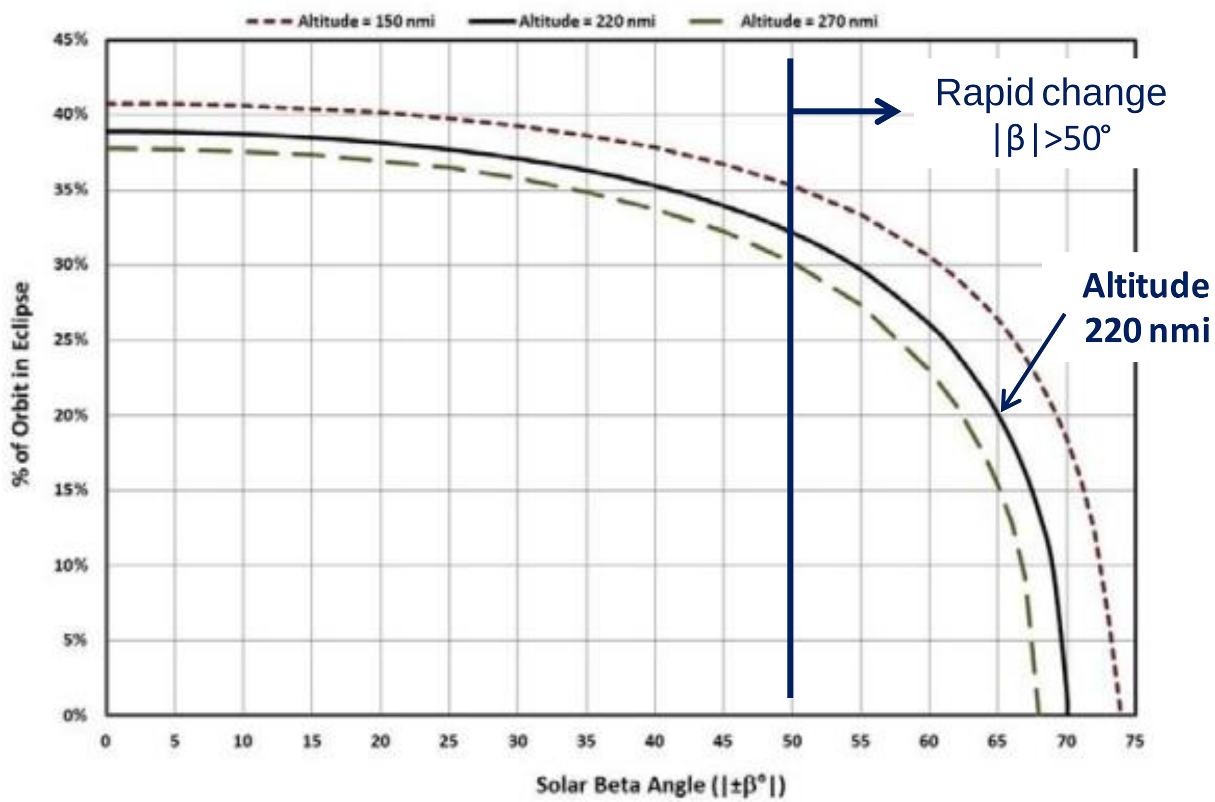


- Beta Range -75° to +75°
- Frequency
  - |Beta Angle| ≤ 50° for 292 days
  - 50° < |Beta Angle|≤ 60° for 37 days
  - |Beta Angle| > 60° for 36 days

ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Solar Beta Angle

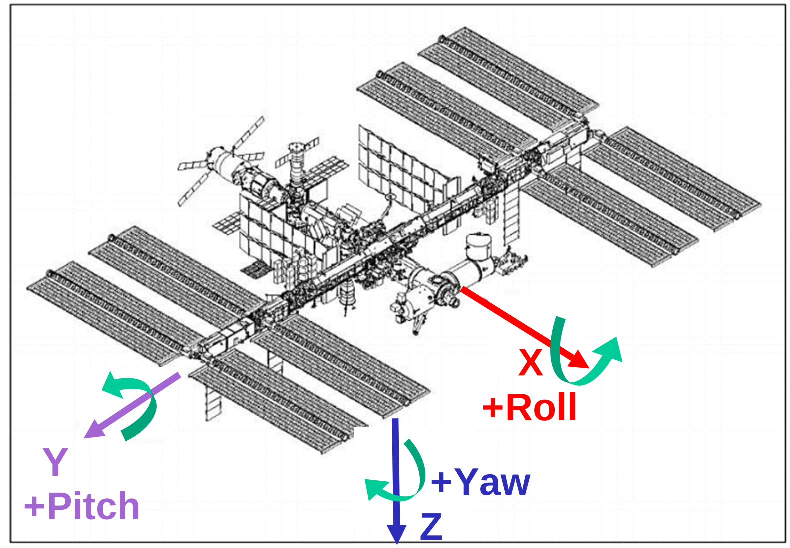
- X-Axis: Solar Beta Angle
- Y-Axis: % of orbit in eclipse or night pass
- |β|>50°, % in eclipse changes rapidly
- |β|>70°, for 220 nmi, % in eclipse is 0% or all sun



ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Flight Orientation/Attitude

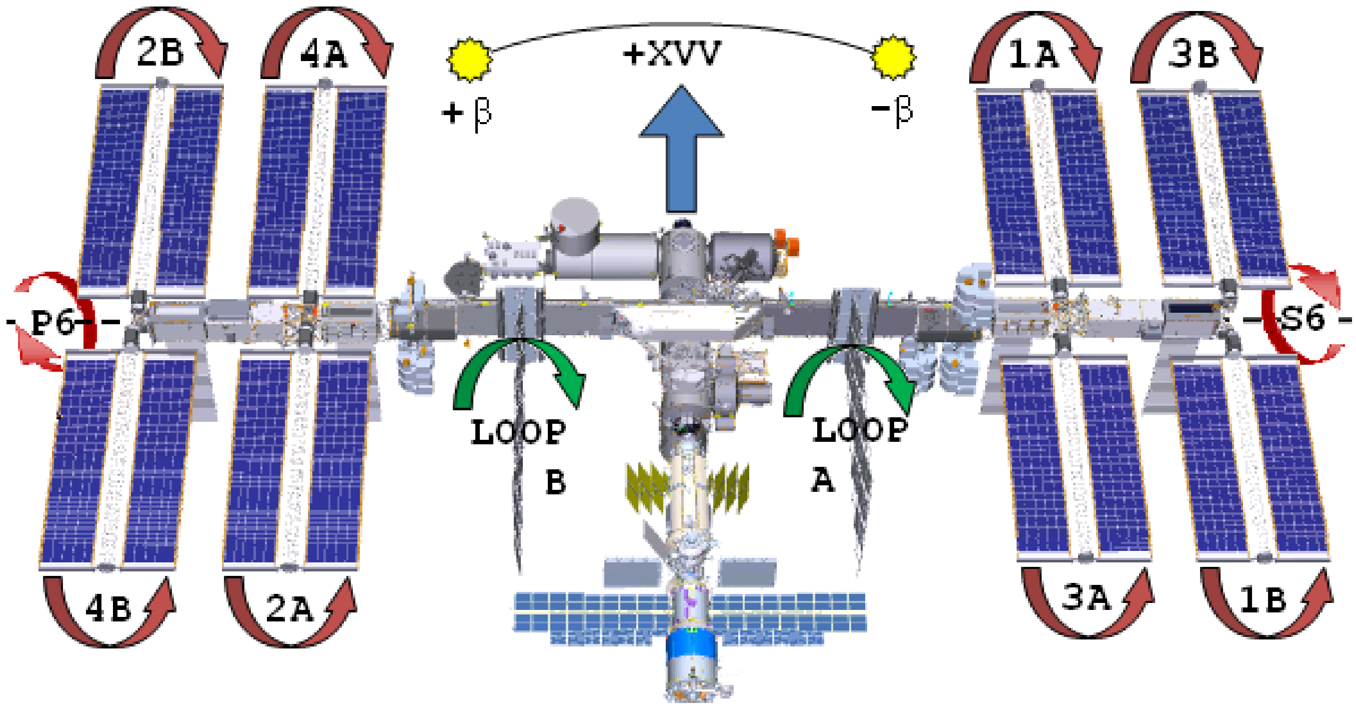
- ISS attitudes (approved)
  - ISS +X axis aligned towards the Velocity Vector (XVV)
    - No time limit
  - ISS +Y axis aligned towards the Velocity Vector (YVV)
    - Thermally unlimited, but operationally limited to less than 100 hours a year
  - ISS +Z axis aligned towards the Velocity Vector (ZVV)
    - 3 hours time limit (attitude used for Russian vehicle dockings)
- ISS orientation gives the rotation angle about each ISS coordinate system axis
  - +X axis (Roll)
  - +Y axis (Pitch)
  - +Z axis (Yaw)



ISS Attitude Name	Attitude Reference Frame	Solar Beta Range (β)	Yaw	Pitch	Roll	Time in Attitude
+XVV +Z Nadir	LVLH	$-75° \leq \beta \leq +75°$	-15° to +15°	-20° to +15°	-15° to +15°	No Limit
-XVV +Z Nadir	LVLH	$-75° \leq \beta \leq +75°$	+165° to +195°	-20° to +15°	-15° to +15°	No Limit
+YVV +Z Nadir	LVLH	$-75° \leq \beta \leq +10°$	-110° to -80°	-20° to +15°	-15° to +15°	No Limit
-YVV +Z Nadir	LVLH	$-10° \leq \beta \leq +75°$	+75° to +105°	-20° to +15°	-15° to +15°	No Limit
+ZVV –X Nadir	LVLH	$-75° \leq \beta \leq +75°$	-15° to +15°	+75° to +105°	-15° to +15°	3 Hours
-ZVV –X Nadir	LVLH	$-75° \leq \beta \leq +75°$	+165° to +195°	+75° to +105°	-15° to +15°	3 Hours

ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Rotating Surfaces

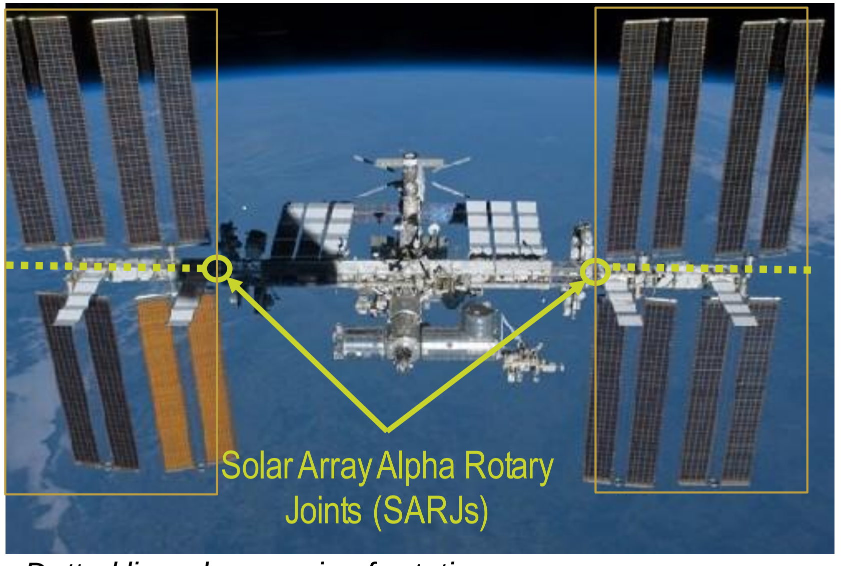


- The ISS has 12 rotational joints which allows pointing of selective ISS surfaces
  - The Beta Gimbal Assemblies (BGAs) are labeled 1A, 1B, 2A, 2B, 3A, 3B, 4A, and 4B
  - The Solar Alpha Rotary Joints (SARJs) are labeled P6 & S6
  - The Thermal Radiator Rotary Joints (TRRJs) are labeled Loop A & Loop B
- Any of these joints can be locked at a fixed position or vary as a function of orbit position

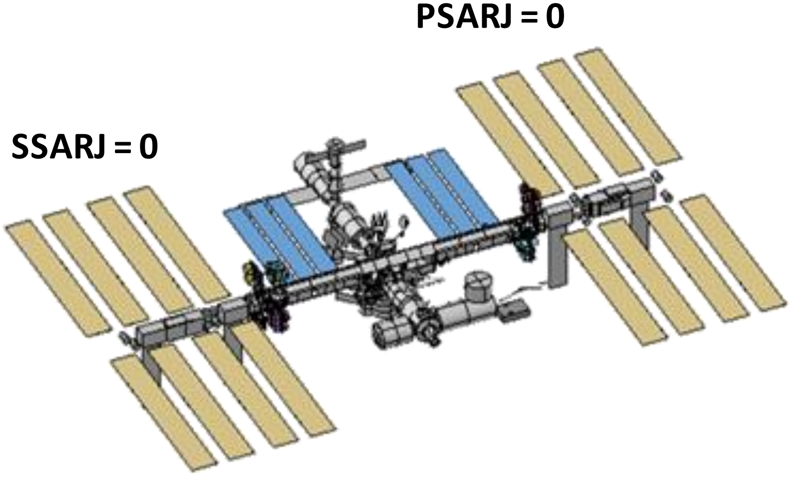
ISS Parameters Impacting Thermal Environments

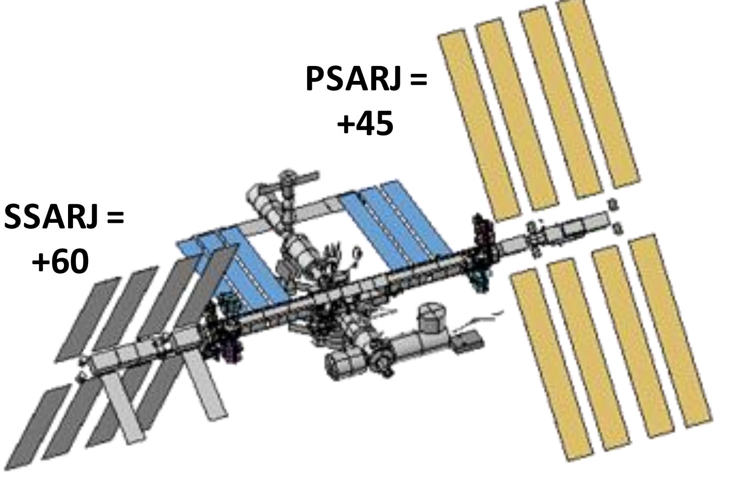
ISS Environmental Drivers: Rotating Surfaces

- Types of Rotating Joints
  - **Solar Alpha Rotary Joints (SARJs)**
  - Beta Gimbal Assemblies (BGAs)
  - Thermal Radiator Rotary Joints (TRRJs)



Dotted line shows axis of rotation



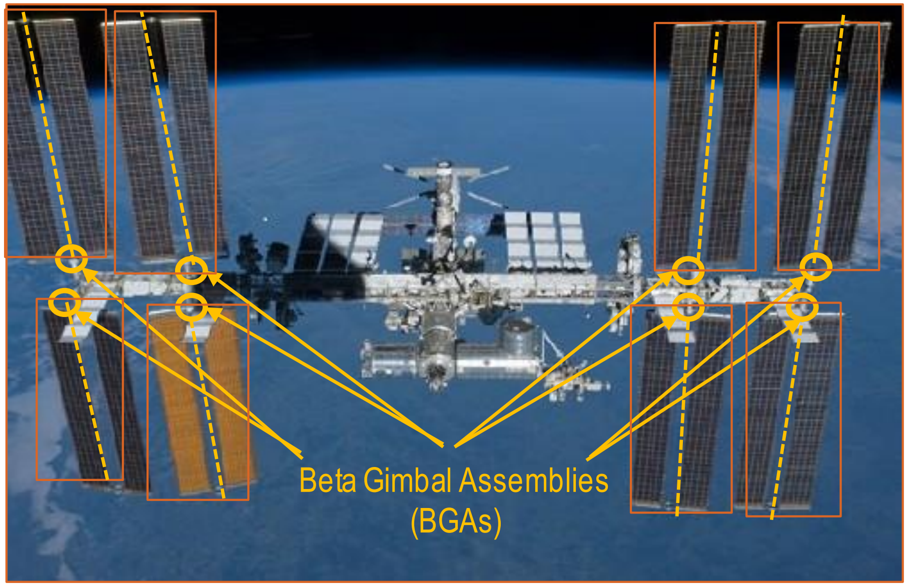


SSARJ = Starboard SARJ
PSARJ = Port SARJ

ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Rotating Surfaces

- Types of Rotating Joints
  - Solar Alpha Rotary Joints (SARJs)
  - **Beta Gimbal Assemblies (BGAs)**
  - Thermal Radiator Rotary Joints (TRRJs)



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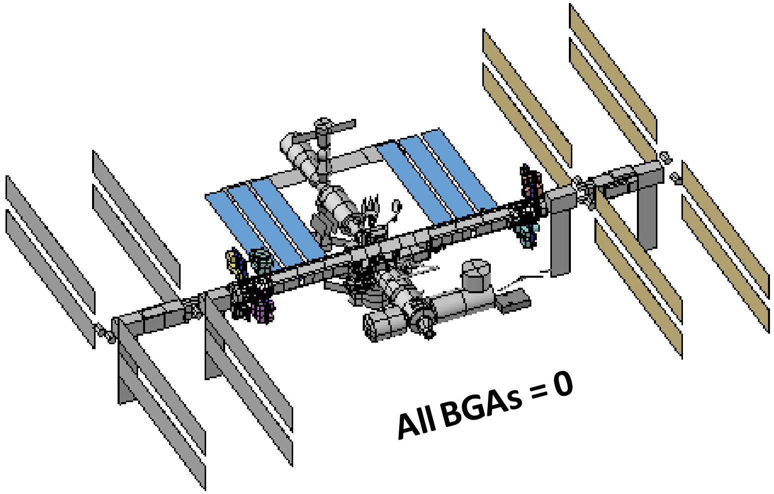

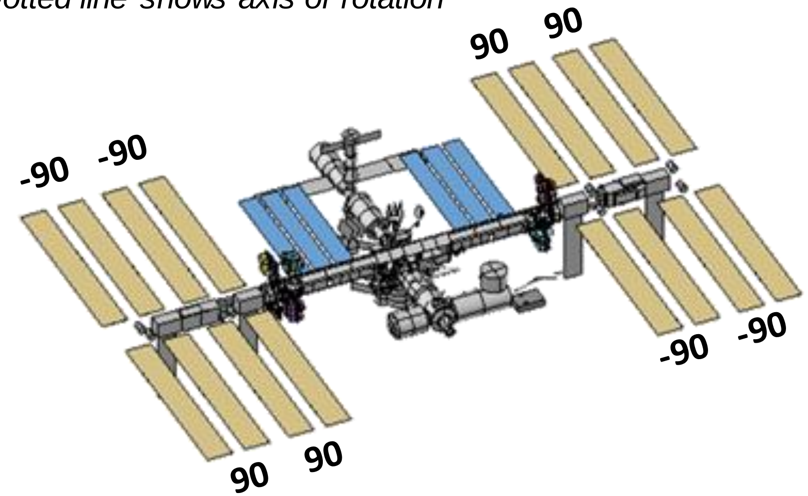

ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Rotating Surfaces

- Types of Rotating Joints
  - Solar Alpha Rotary Joints (SARJs)
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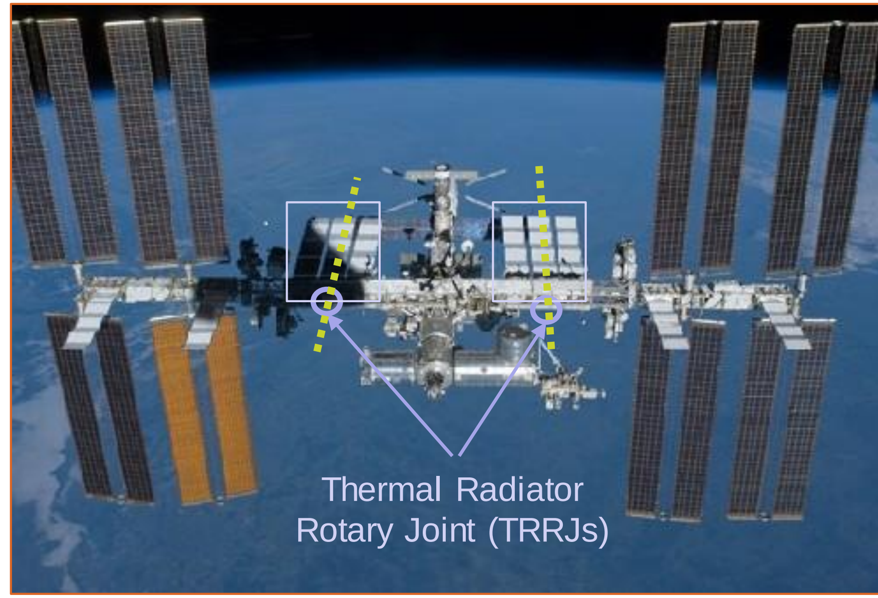
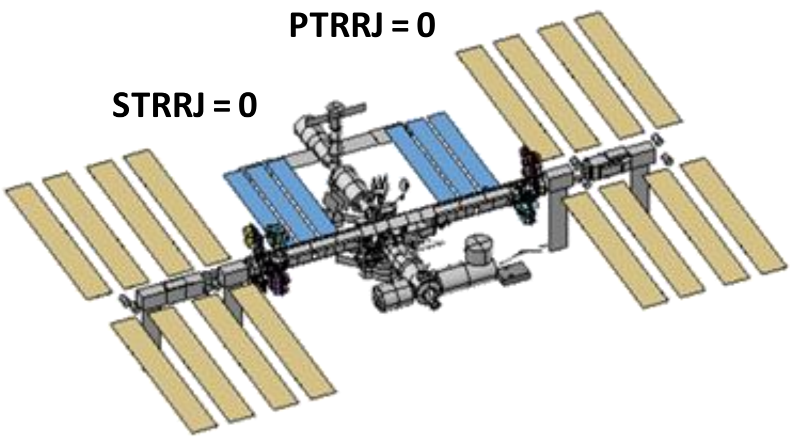
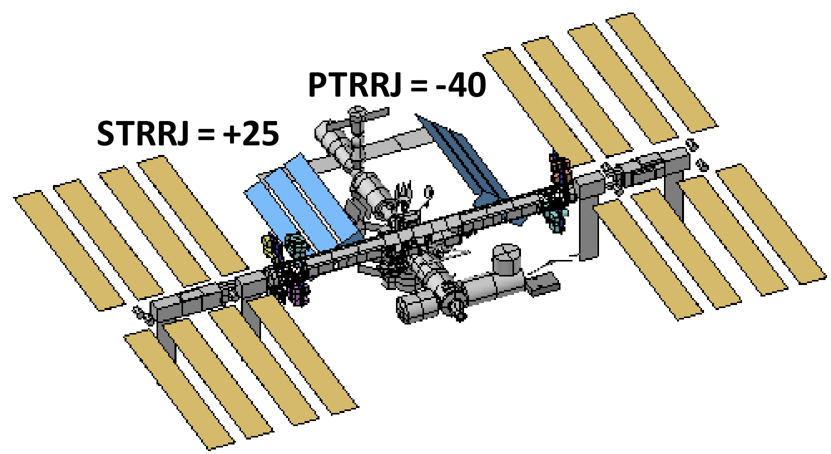
  - **Thermal Radiator Rotary Joints (TRRJs)**



Dotted line shows axis of rotation

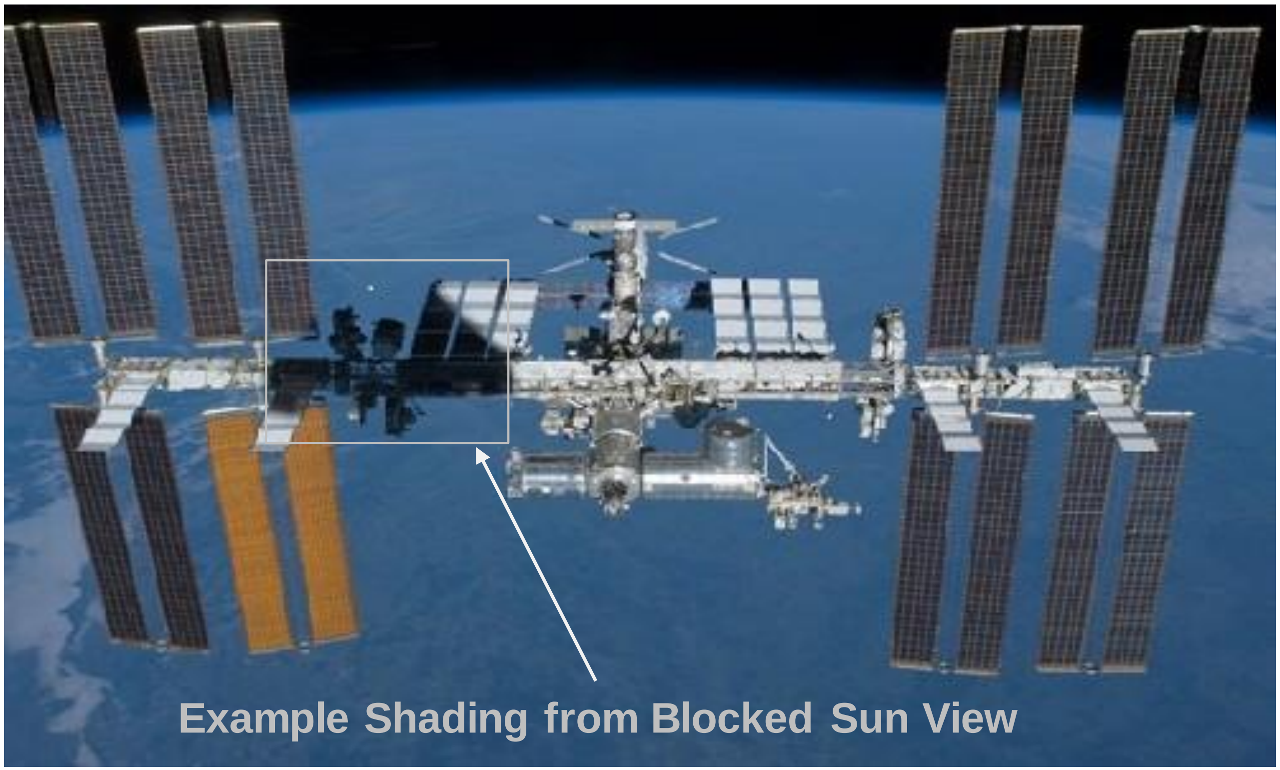


SSARJ = Starboard SARJ
PSARJ = Port SARJ



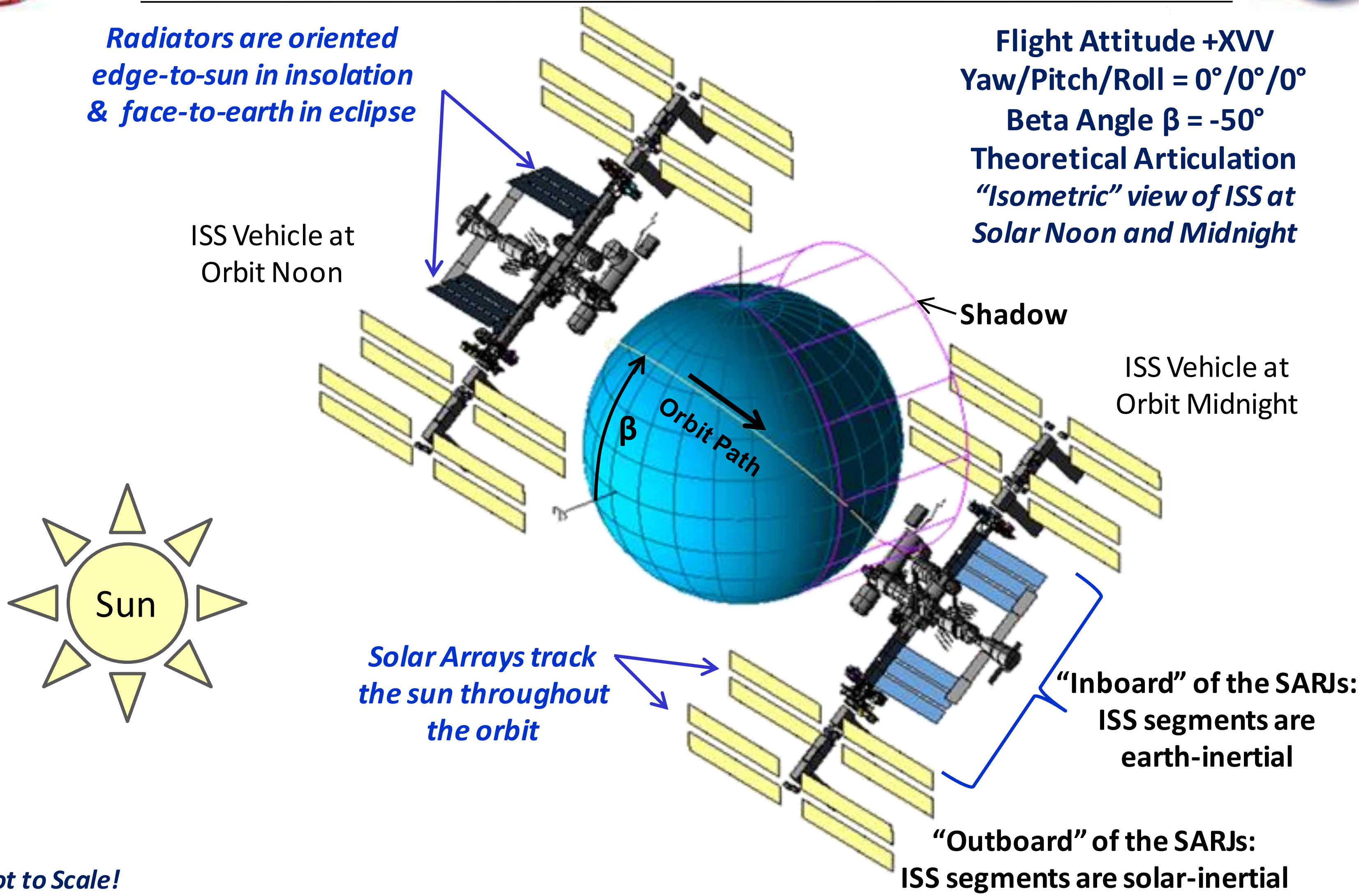
ISS Parameters Impacting Thermal Environments

ISS Environmental Drivers: Rotating Surfaces



- Impact on thermal environment
  - Rotating joints position solar and thermal arrays
  - Shade or block the view from the sun or deep space

ISS Orbit Illustration



Not to Scale!
The entire ISS Vehicle is either all in sun, or all in eclipse

Orbit Videos (Viewed From Sun)

1. +XVV, Beta -50, YPR = 0°/0°/0°, Theoretical Articulation
2. +XVV, Beta 0, YPR = -4°/-2°/1°, locked TRRJs
3. +YVV, Beta -75, YPR = -90°/0°/0°, locked SARJs and TRRJs
4. +ZVV, beta 75, YPR = 0°/90°/0°, locked SARJs and TRRJs

ISS Parameters Impacting Thermal Environments

Sink Temperature

- The instantaneous radiation sink temperature (T_s) for an optically opaque surface is defined as the temperature the surface will come to if no thermal influences act on it other than radiation (i.e., energy absorbed = energy emitted)

- The energy absorbed by, and emitted from, the surface per unit area and per unit time is expressed as

$$q_{absorbed} = \alpha_s q_s + \varepsilon_{IR} \, q_{IR} \quad \text{and} \quad q_{emitted} = \varepsilon_{IR} \, \sigma T_s^4$$

- Setting these equal and solving for T_s yields

$$T_s = \{ [q_s (\alpha_s / \varepsilon_{IR}) + q_{IR}] / \sigma \}^{1/4}$$

where q_s = *solar-spectrum incident flux from all sources, W/m²*

q_{IR} = *infrared-spectrum incident flux from all sources, W/m²*

α_s = *solar absorptivity,* ε_{IR} = *infrared emissivity*

σ = *Stefan-Boltzmann constant = 5.67 E-8 W/m²-K⁴*

T_s = *Surface temperature, K*

ISS Parameters Impacting Thermal Environments

Sink Temperature

$$T_s = \{ [q_s (\alpha_s/\varepsilon_{IR}) + q_{IR}] / \sigma \}^{1/4}$$

- For a given thermal environment, the sink temperature of an object is a function of the surface optical property ratio ($\alpha_s/\varepsilon_{IR}$)
- The sink temperature is also related to the solar and infrared incident flux from all sources, q_s and q_{IR} , which have direct and reflected components
  - Orbital components: Solar, Albedo & IR flux
  - Energy exchange from ISS surfaces: a function of the ISS surface optical properties, surface temperature and radiative view factors
- The computations are performed with thermal analytical models

ISS Parameters Impacting Thermal Environments

Design Verification Summary

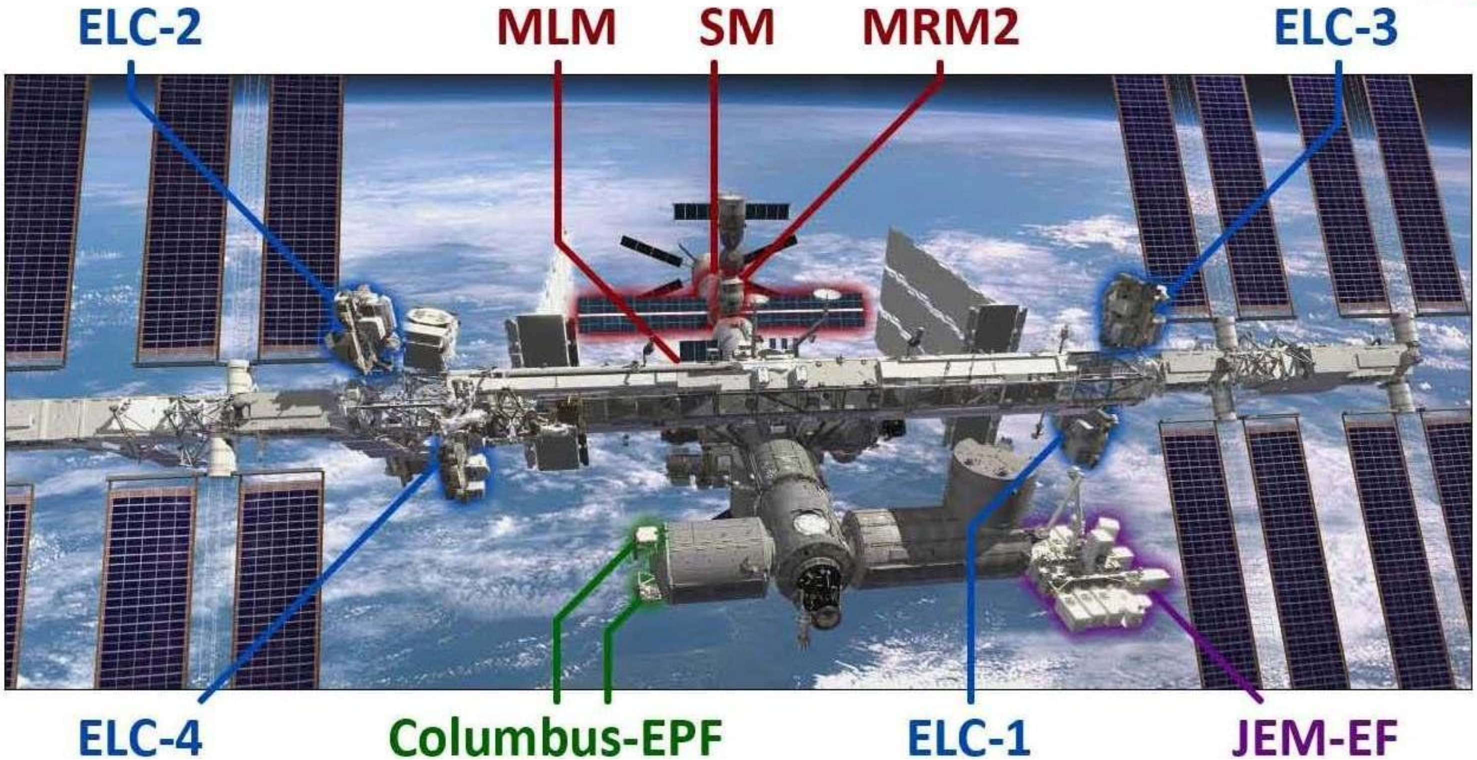
Parameters	Cold Value	Hot Value	Reference
Solar Constant	1321 W/m^2 (418 $Btu/hr\text{-}ft^2$)	1423 W/m^2 (451 $Btu/hr\text{-}ft^2$)	SSP 41000, Section 3.2.6.1.1
Albedo	0.2	0.4	SSP 41000, Section 3.2.6.1.1
Earth's Radiation, Outgoing Longwave Radiation (OLR)	206 W/m^2 (65 $Btu/hr\text{-}ft^2$)	286 W/m^2 (90.7 $Btu/hr\text{-}ft^2$)	SSP 41000, Section 3.2.6.1.1
Altitude	270 nmi (Design Verification)	150 nmi (Design Verification)	SSP 41000
	215nmi (Operational Planning)	215nmi (Operational Planning)	
Beta Angle	Full beta angle range	Full beta angle range	SSP 50699-03, (Design Verification)
			MCC Flight Planning (Operational Planning)
Plume Heating	Not analyzed (Design Verification)	ISS Plume Heating Zonal Map (Design Verification)	PIRN 57003-NA-0138A (Design Verification)
	Not analyzed (Operational Planning)	Not analyzed (Operational Planning)	Engineering Judgment (Operational Planning)

ISS Parameters Impacting Thermal Environments

Design Verification Summary (Continued)

Parameters	Cold Value	Hot Value	Reference
Flight Attitude	Full YPR envelope (Design Verification)	Full YPR envelope (Design Verification)	SSP 50699-03, (Design Verification)
	Per timeline (Operational Planning)	Per timeline (Operational Planning)	MCC Flight Planning (Operational Planning)
Flight Orientation	XVV, YVV, ZVV (Design Verification)	XVV, YVV, ZVV (Design Verification)	SSP 50699-03, (Design Verification)
	Per timeline (Operational Planning)	Per timeline (Operational Planning)	MCC Flight Planning (Operational Planning)
Articulation	Full rotation with perfect (theoretical) pointing with consideration of parking effects (Design Verification)	Full rotation with perfect (theoretical) pointing with consideration of parking effects (Design Verification)	Engineering Judgment (Design Verification)
	Per timeline (Operational Planning)	Per timeline (Operational Planning)	MCC Flight Planning (Operational Planning)
Optical Properties	BOL (extreme including manufacturing tolerances) (Design Verification)	EOL (extreme including manufacturing tolerances) (Design Verification)	To be determined by the payload developer
	BOL (nominal) (Operational Planning)	EOL (nominal) (Operational Planning)	

External Facilities and Platforms

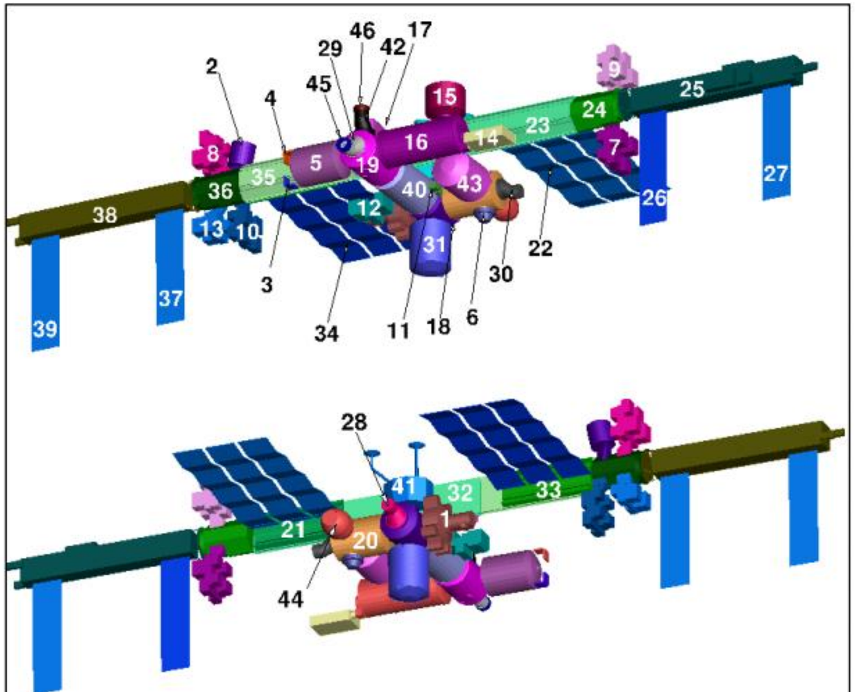


ELC = ExPRESS Logistic Carriers
MRM = Russian Mini Research Module
SM = Russian Service Module
JEM-EF = Japanese Experiment Module – Exposed Facility
Columbus-EPF = European Columbus External Payload Facility

ISS Parameters Impacting Thermal Environments

Design Verification Summary (Continued)

- Potential plume impingement from thrusters of visiting vehicles in ISS approach or separation
- Zone number on map corresponds to table value of heat flux
- Constant heat flux is applied for 7.83 seconds for total heat load



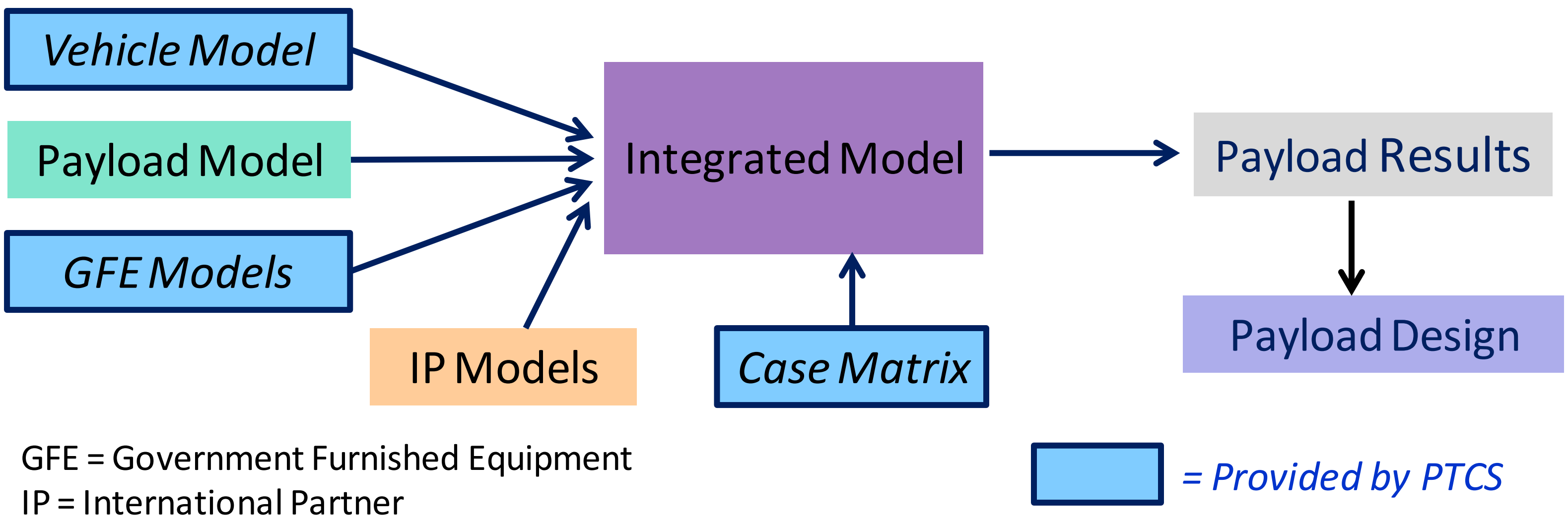
ISS Plume Heating Zonal Map

4. Integrated Thermal Analysis

David Farner

Integrated Thermal Analysis

Integrated Thermal Analysis Process



GFE = Government Furnished Equipment
IP = International Partner

- The vehicle model will be provided by ISS PTCS and will include a reduced fidelity model of the launch vehicle and ISS
  - Model will be in Thermal Desktop format with English units
  - PTCS is responsible model maintenance/configuration control
- The ISS case matrix provides representative ISS environments
- Payload developers are responsible for adding additional cases if needed, based on a payload's specific thermal performance

Integrated Thermal Analysis

Example of ISS +XVV Case Matrix

Case	Yaw	Pitch	Roll	Betas	Environment	Model Runs
1	-4	-2	1	+75, +60, +30, 0, -30, -60, -75	Cold	7
2	15	15	15	+75, +60, +30, 0, -30, -60, -75	Cold	7
3	15	15	-15	+75, +60, +30, 0, -30, -60, -75	Cold	7
4	15	-20	15	+75, +60, +30, 0, -30, -60, -75	Cold	7
5	15	-20	-15	+75, +60, +30, 0, -30, -60, -75	Cold	7
6	-15	15	15	+75, +60, +30, 0, -30, -60, -75	Cold	7
7	-15	15	-15	+75, +60, +30, 0, -30, -60, -75	Cold	7
8	-15	-20	15	+75, +60, +30, 0, -30, -60, -75	Cold	7
9	-15	-20	-15	+75, +60, +30, 0, -30, -60, -75	Cold	7

- PTCS maintains a recommended case matrices for known ISS attitudes such as +XVV, +YVV, and +ZVV
  - For both YVV and ZVV attitudes, the matrix will also include park angles for SARJ and TRRJ joints
- The approach has a payload developer making first pass using cold environmental parameters and then selecting “maximum” cold case results to repeat with hot environmental parameters for a total of 89 cases
- These case matrices will provide payload developer representative ISS environments, but payload developer is responsible for running additional analysis cases if needed

Integrated Thermal Analysis

- Additional PTCS materials
  - Document JSC-66617 [ISS Passive Thermal Control Systems (PTCS) Analysis Guide] has additional details about ISS modeling practices/assumptions
    - This document also contains template/expectations for thermal model deliveries to ISS program
  - Model package will include documentation to support thermal analysis (i.e. model settings, simulating ISS attitudes, etc.)
  - Thermal models of selected GFE items such as grapple fixtures, FRAM, antennas, etc. can be provided to a payload developer
    - JAXA is responsible for the PIU thermal model
- PTCS data transfer to a payload developer is through EDMS system
  - Latest versions of models will be kept on EDMS
  - Once a payload assigned to a Payload Integration Manager (PIM), the PIM can get payload developer access to EDMS
- PTCS will provide support for model/analysis issues subject to PTCS schedule/resource considerations

5. Representative Environments

David Farner

Representative ISS Environments

- The thermal environment an external payload may experience after installation on ISS has contributions from both the ISS exterior surfaces temperatures and the payload orbital heating rates
- As noted in the previous sections, many parameters such as ISS geometry, optical properties, ISS attitude, solar beta angle, ISS articulating surfaces, etc. may impact both ISS exterior temperatures and payload orbital heating rates
- Payload exterior geometry and optics also impacts payload orbital heating rates
- This section will present environment data for all four ELC locations as well as the JEM airlock (JEMAL) outer hatch for a fixed ISS attitude across selected solar beta angles
  - ISS Attitude is +XVV with YPR = (-4°, -2°, +1°)
  - Solar beta angles of ±75°, ±60°, ±45°, ±30°, & 0°
- The environment will be calculated using the EVA database. The EVA database includes all the ISS parameters discussed in section 3

ISS EVA Database Summary

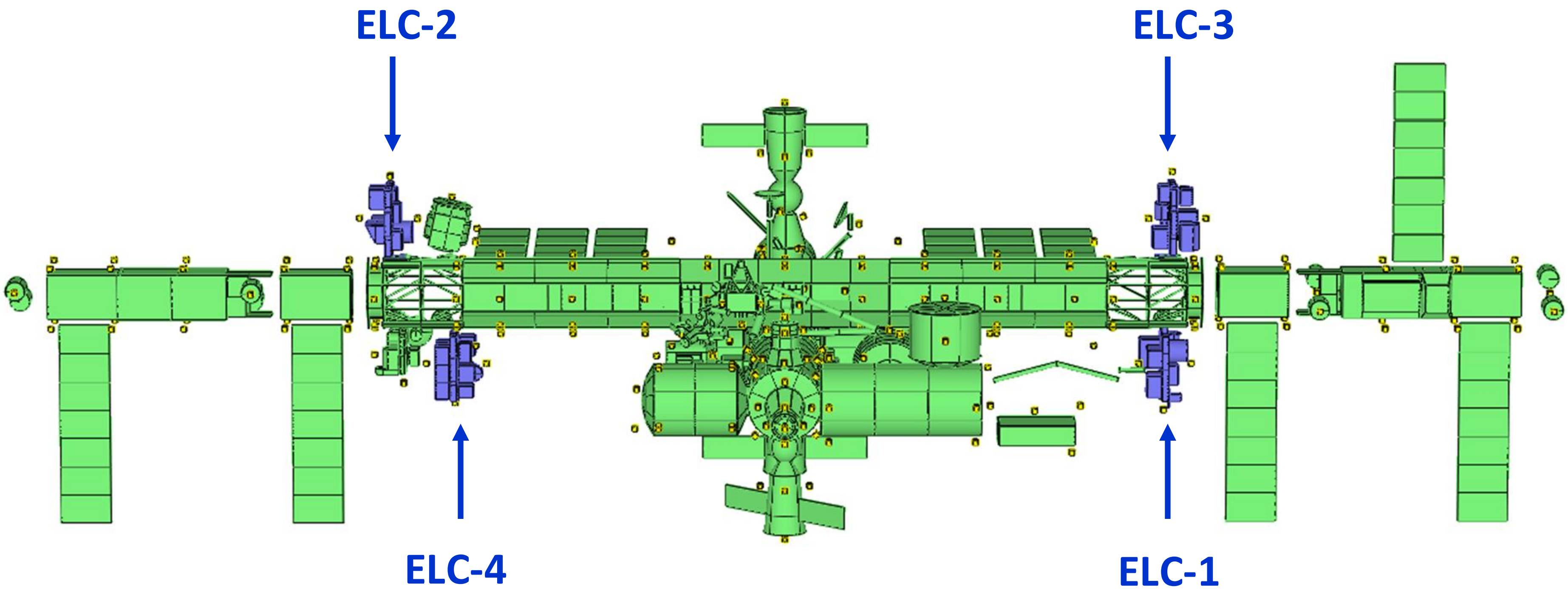
- ISS EVA thermal environment database is maintained by the EVA Section of the EC2 Design & Analysis Branch at JSC
- ISS EVA thermal environment database was developed to support EVA worksite analysis
- Database uses flux cubes to sample environment at potential ISS worksite locations
  - Flux is computed as 6-sided average (**payload geometry may be significantly different**)
  - Flux cube size is 1 x 1 x 1 feet
  - Flux cube is placed ~ 1.5 feet away from ISS structure
- Processing logic has been developed to calculate the average flux for the following time intervals:
  - Day Pass ~ 1 hour
  - Night Pass ~ 0.5 hours
  - Orbit ~ 1.5 hours
  - Day/Night Pass data only available for solar beta range from -60° to +60°, but Orbit data includes solar beta range -75° to +75°

ISS EVA Database Summary (Continued)

- At each ELC location there are 3 flux cubes
  - An outboard position
  - An inboard position
  - Either Zenith/Nadir position depending on ELC location
- Processing logic has been developed to generate summary tables for 3 optical property ratios
  - Optical Property Ratio 1 (α/ε) = 0.18/0.84 ~ 0.21
  - Optical Property Ratio 2 (α/ε) = 0.66/0.74 ~ 0.89
  - Optical Property Ratio 3 (α/ε) = 0.45/0.12 ~ 3.75
- Flux cube thermal analysis parameters
  - Orbit altitude = 216 nautical miles
  - <u>End of life (EOL) optics</u>
  - Mean values for solar/albedo/OLR = 434.6 BTU/hr-ft2/0.27/76.4 BTU/hr-ft2
  - Surface articulation
    - Nominal tracking for port/starboard SARJ and solar arrays
    - TRRJ locked at -40° for port side & +25° for starboard side

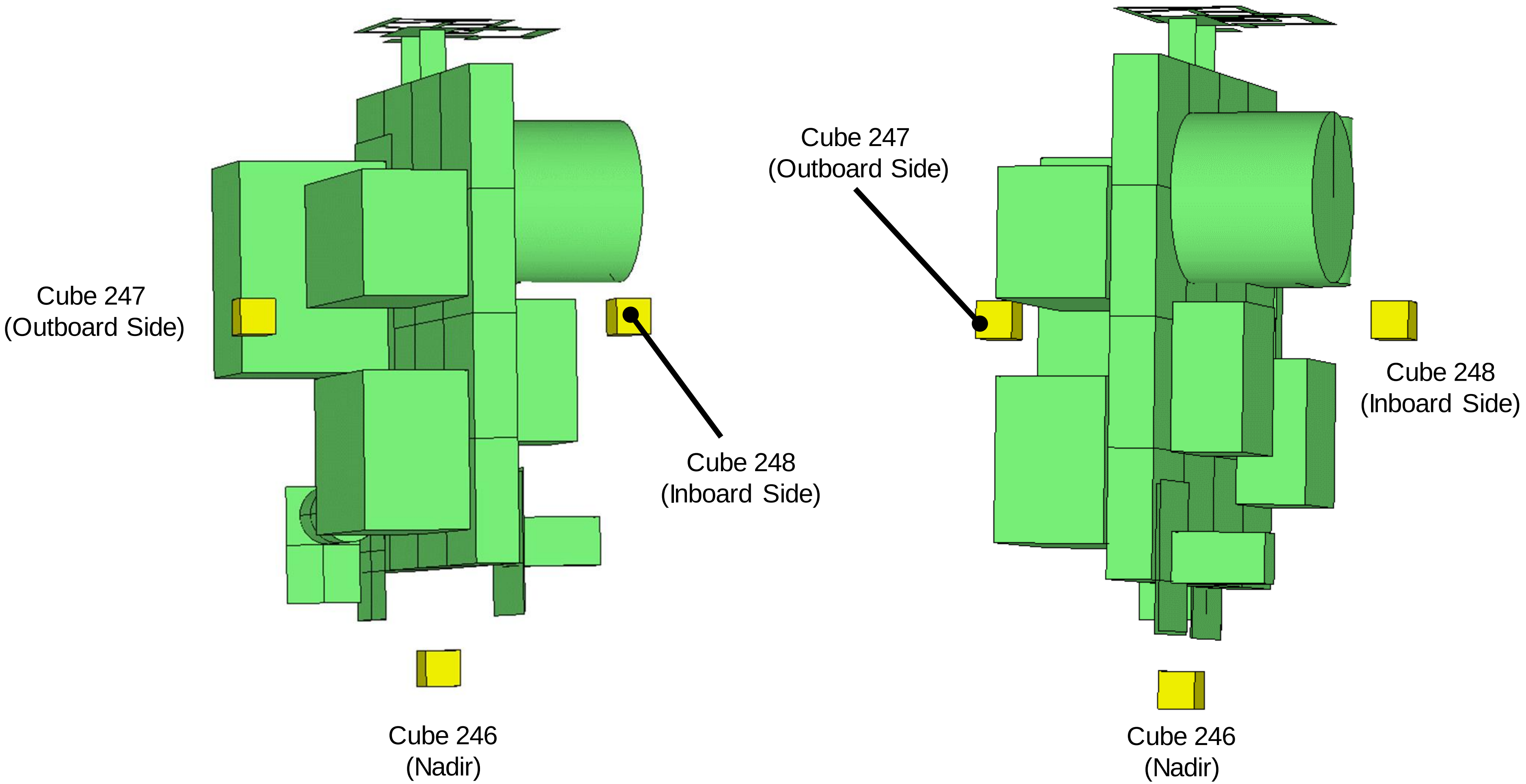
Representative ISS Environments

Example of ISS Geometry used in the EVA Database



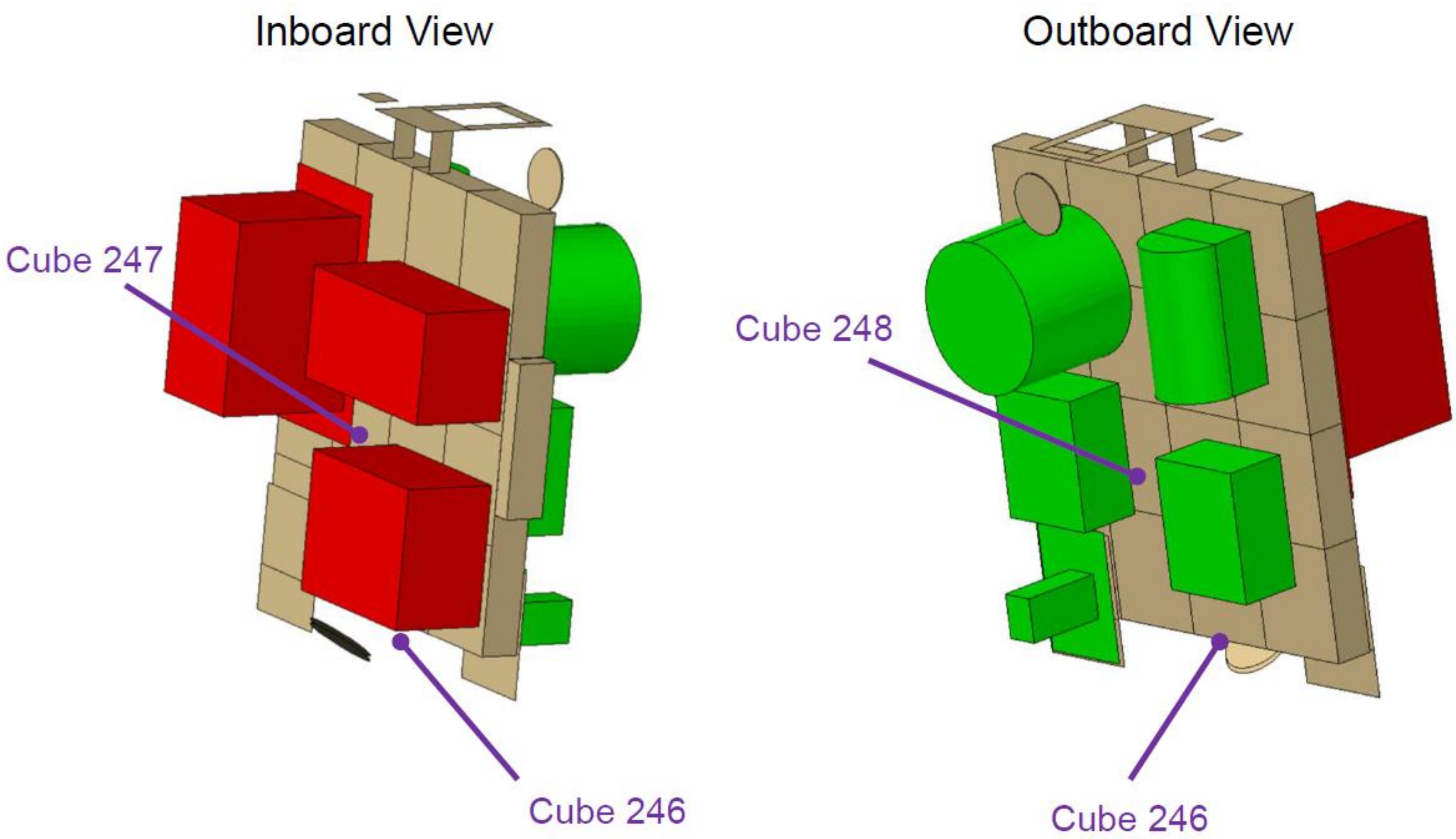
Note – Solar Array Wings not shown
Environment sampled at 254 ISS locations

Flux Cubes around ELC-1



Representative ISS Environments

ELC-1 Geometry (Nadir, Port)



Note – payload/ORU configuration can vary between inboard and outboard sides

Representative ISS Environments

ELC-1 Environment Summary Tables for +XVV YPR = (-4°, -2°, +1°)

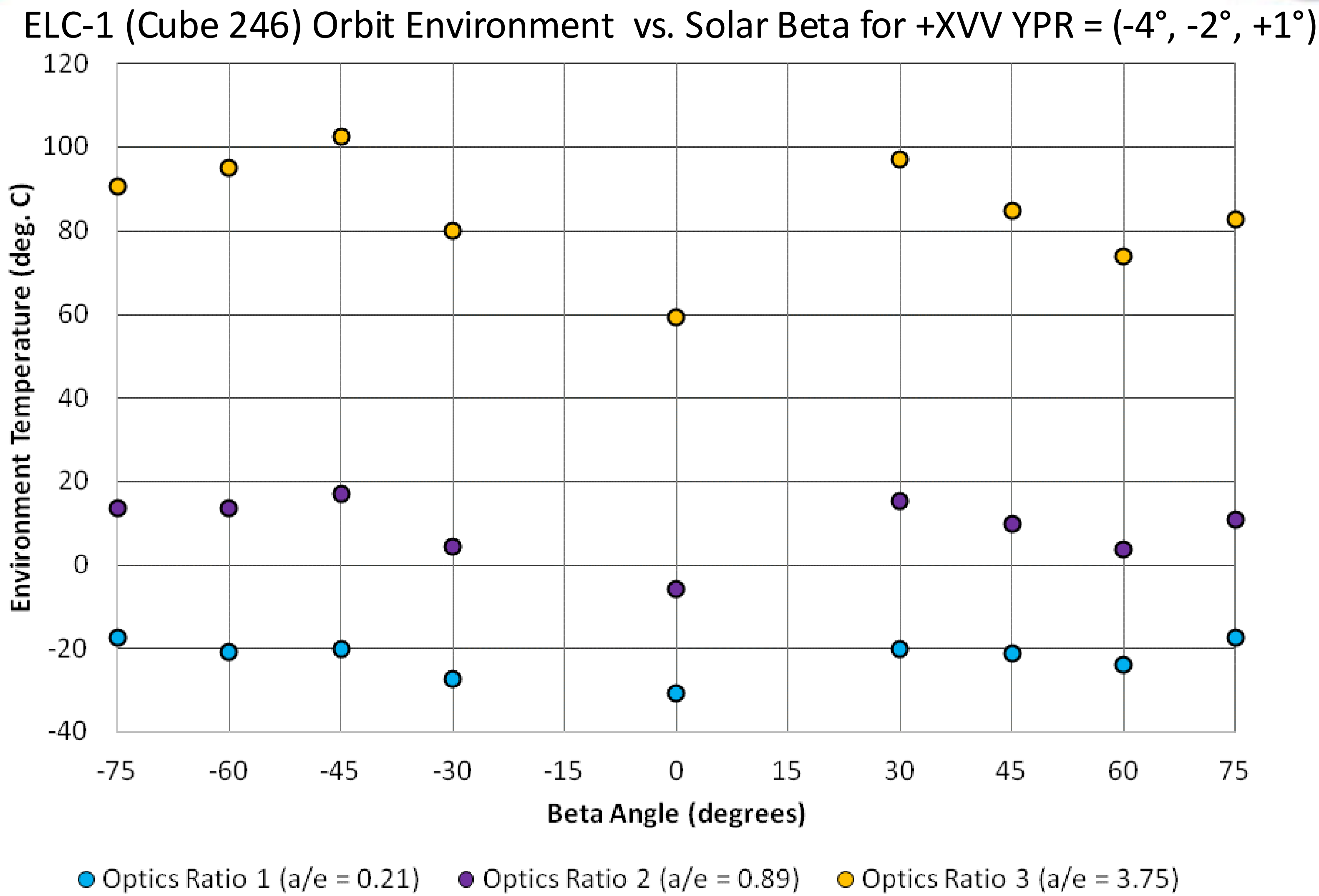
Location	Optical Ratio 1(α/ε = 0.18/0.84 = 0.21)						Optical Ratio 2(α/ε = 0.66/0.74 = 0.89)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)		Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
247 (ELC Inboard)	-46	-39	-23	-3	-27	-12	-46	-39	-11	43	-18	19
246 (Nadir)	-51	-47	-20	-6	-31	-17	-51	-47	14	39	-6	17
248 (ELC Outboard)	-50	-41	-25	12	-31	7	-50	-41	-13	56	-21	39

Location	Optical Ratio 3(α/ε = 0.45/0.12 = 3.75)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper
247 (ELC Inboard)	-46	-39	27	135 *	13	96
246 (Nadir)	-51	-47	96	137 *	59	103
248 (ELC Outboard)	-50	-41	23	155 *	9	119 *

Note – Environment range listed is for trending purposes only and may be significantly different for an actual payload geometry/optics
*** indicates temperature exceeds EVA incidental touch limit (+112.8 C)**

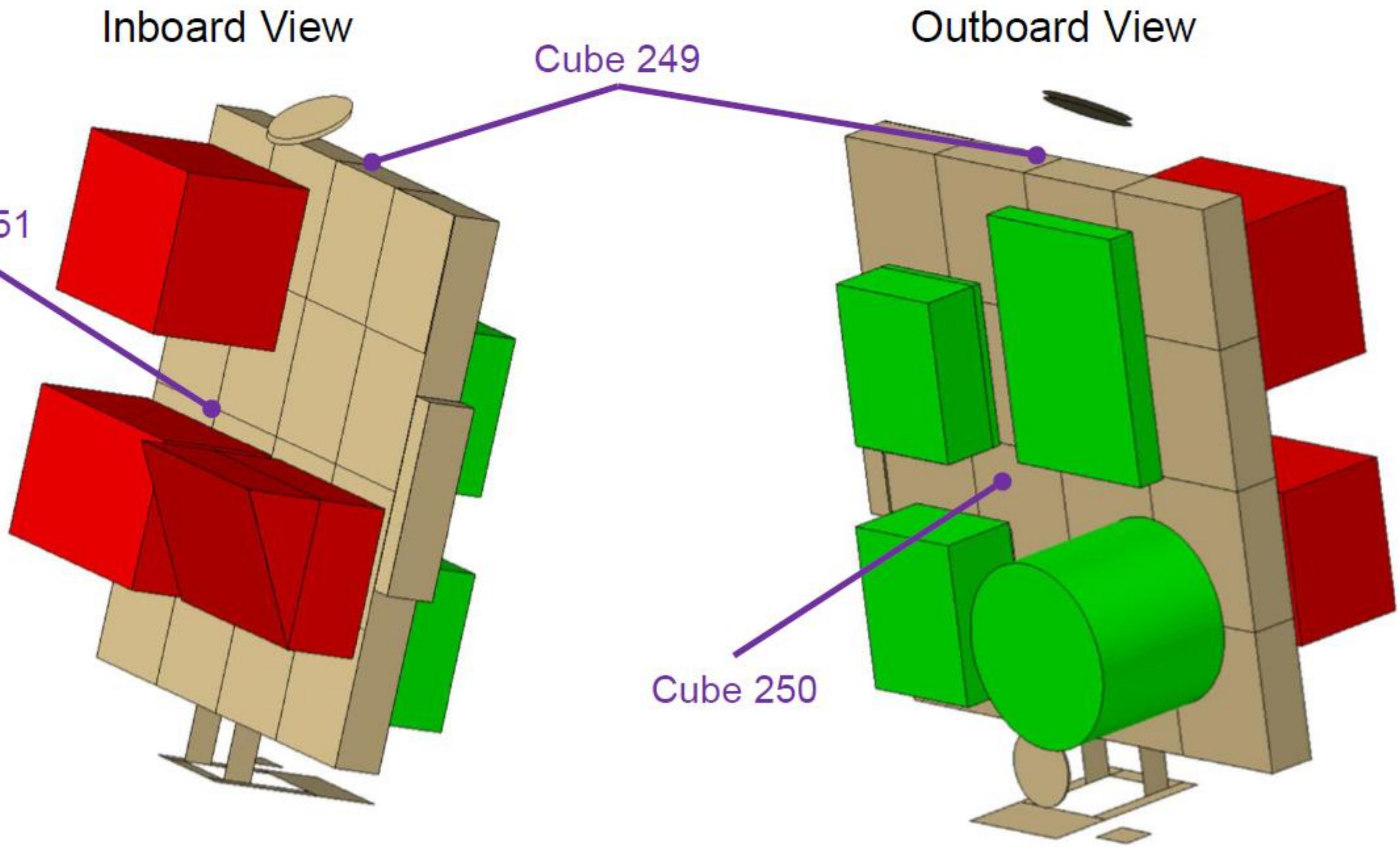
- Tables show how payload environment can vary with solar beta angle as well as optical property ratio
  - Night pass range is independent of optical property ratio since cube receives little or no solar flux
- Optical Ratios 2 & 3 display significant environment range (> 60° C) over solar beta range for both Day & Orbit time intervals for outboard location
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C)

Representative ISS Environments



- Optical Ratio 1 has temperatures ≤ -20° C across most of the solar beta range.

ELC-2 Geometry (Zenith, Starboard)



Note – payload/ORU configuration can vary between inboard and outboard sides

Representative ISS Environments

ELC-2 Environment Summary Tables for +XVV YPR = (-4°, -2°, +1°)

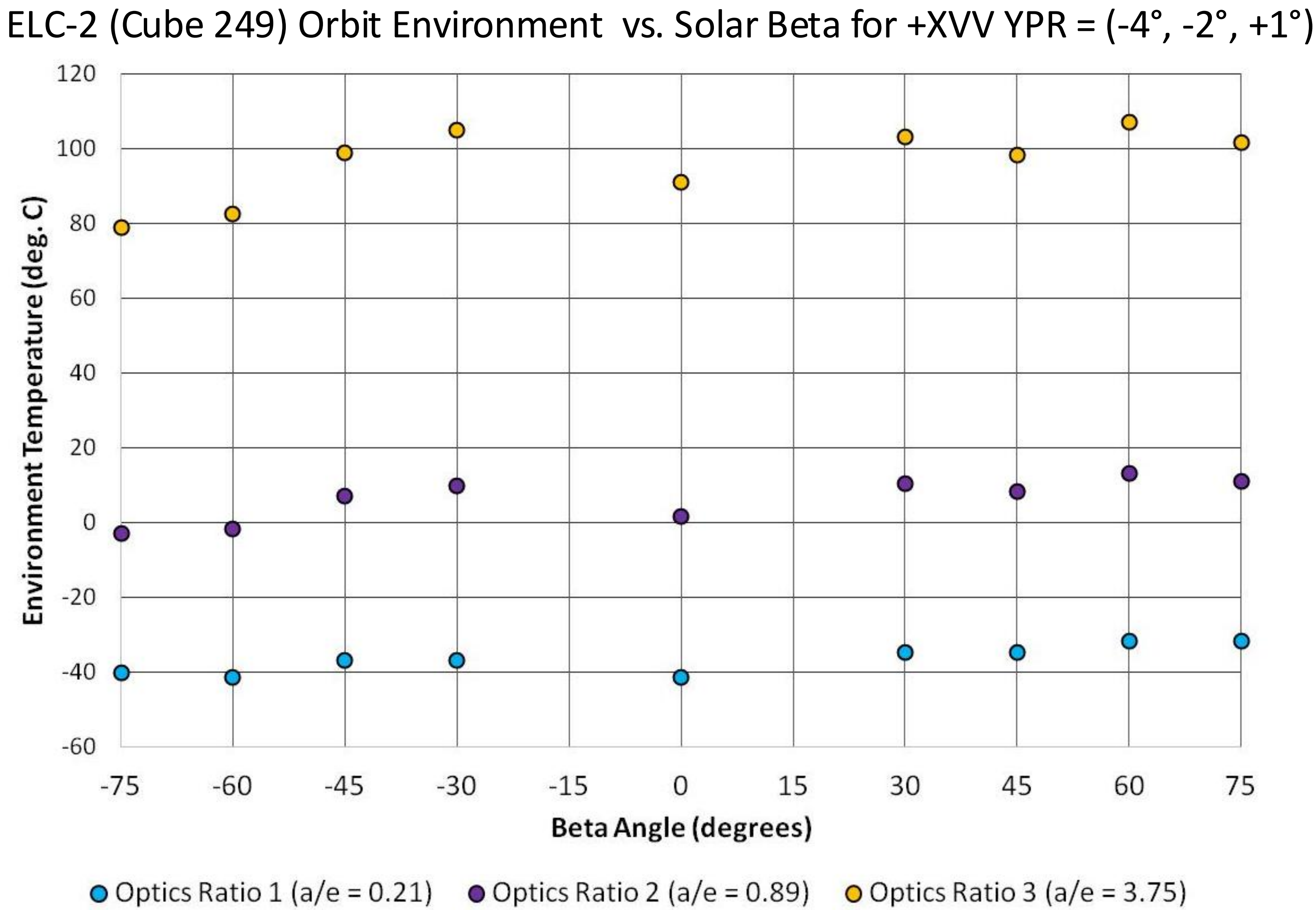
Location	Optical Ratio 1(α/ε = 0.18/0.84 = 0.21)						Optical Ratio 2(α/ε = 0.66/0.74 = 0.89)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)		Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
251 (ELC Inboard)	-63	-57	-28	8	-39	-11	-63	-57	-17	47	-33	21
249 (Zenith)	-89	-83	-30	-16	-41	-32	-89	-83	16	39	-3	13
250 (ELC Outboard)	-73	-62	-28	7	-37	4	-73	-62	-1	53	-24	-44

Location	Optical Ratio 3(α/ε = 0.45/0.12 = 3.75)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper
251 (ELC Inboard)	-63	-57	18	142 *	-9	101
249 (Zenith)	-89	-83	110	148 *	79	107
250 (ELC Outboard)	-73	-62	31	156 *	12	138 *

Note – Environment range listed is for trending purposes only and may be significantly different for an actual payload geometry/optics
*** indicates temperature exceeds EVA incidental touch limit (+112.8 C)**

- Tables show how payload environment can vary with solar beta angle as well as optical property ratio
- An increase in optical property ratio results in an increase in environment range for Day & Orbit time intervals
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C)

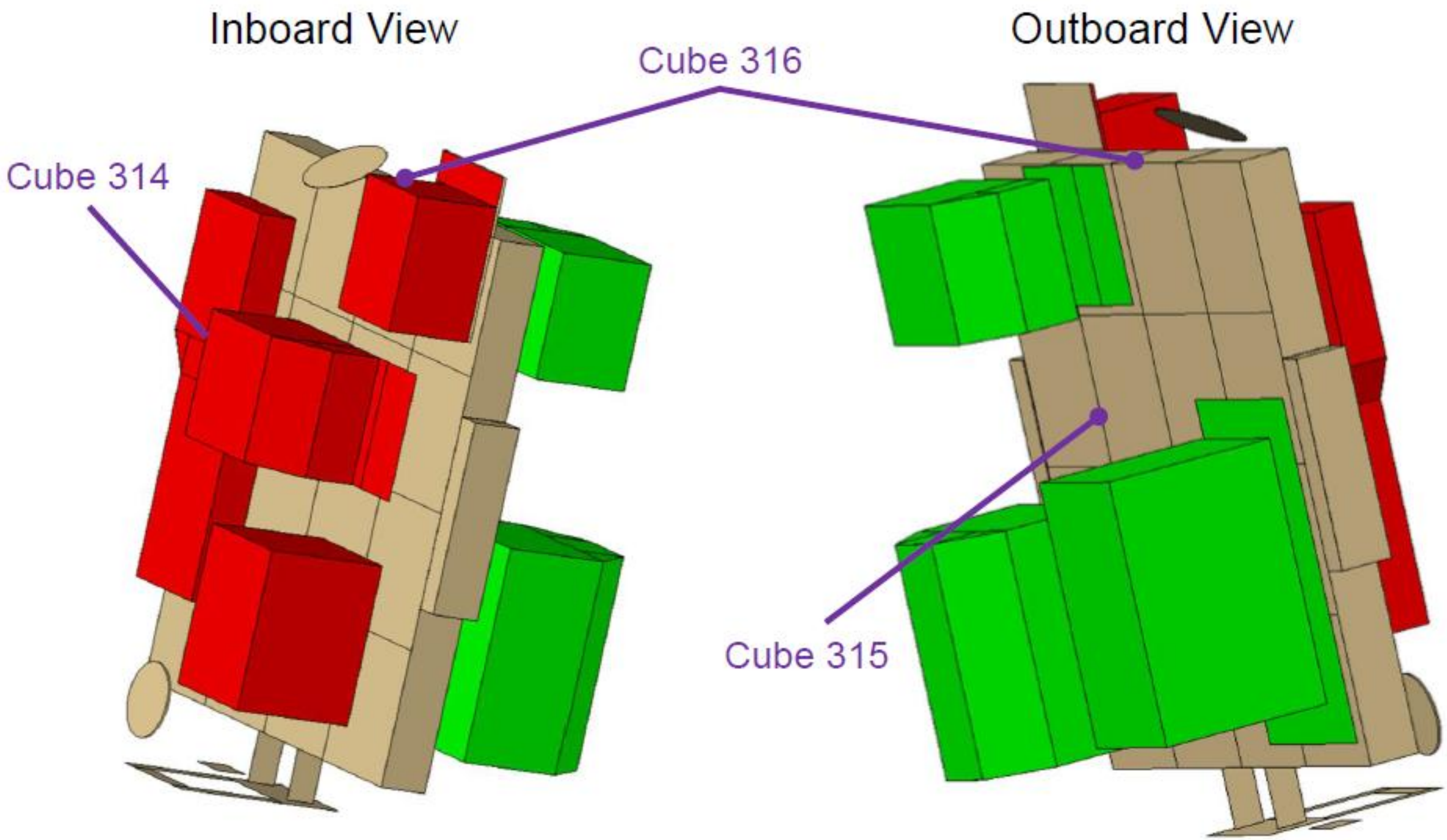
Representative ISS Environments



- Optical Ratio 1 has temperatures ≤ -30° C across the entire solar beta range.

Representative ISS Environments

ELC-3 Geometry (Zenith, Port)



Note – payload/ORU configuration can vary between inboard and outboard sides

Representative ISS Environments

ELC-3 Environment Summary Tables for +XVV YPR = (-4°, -2°, +1°)

Location	Optical Ratio 1(α/ε = 0.18/0.84 = 0.21)						Optical Ratio 2(α/ε = 0.66/0.74 = 0.89)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)		Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
314 (ELC Inboard)	-66	-58	-40	1	-44	-8	-66	-58	-26	54	-33	31
316 (Zenith)	-88	-81	-32	-16	-43	-27	-88	-81	11	38	-7	19
315 (ELC Outboard)	-69	-56	-27	3	-34	-3	-69	-56	-11	50	-21	36

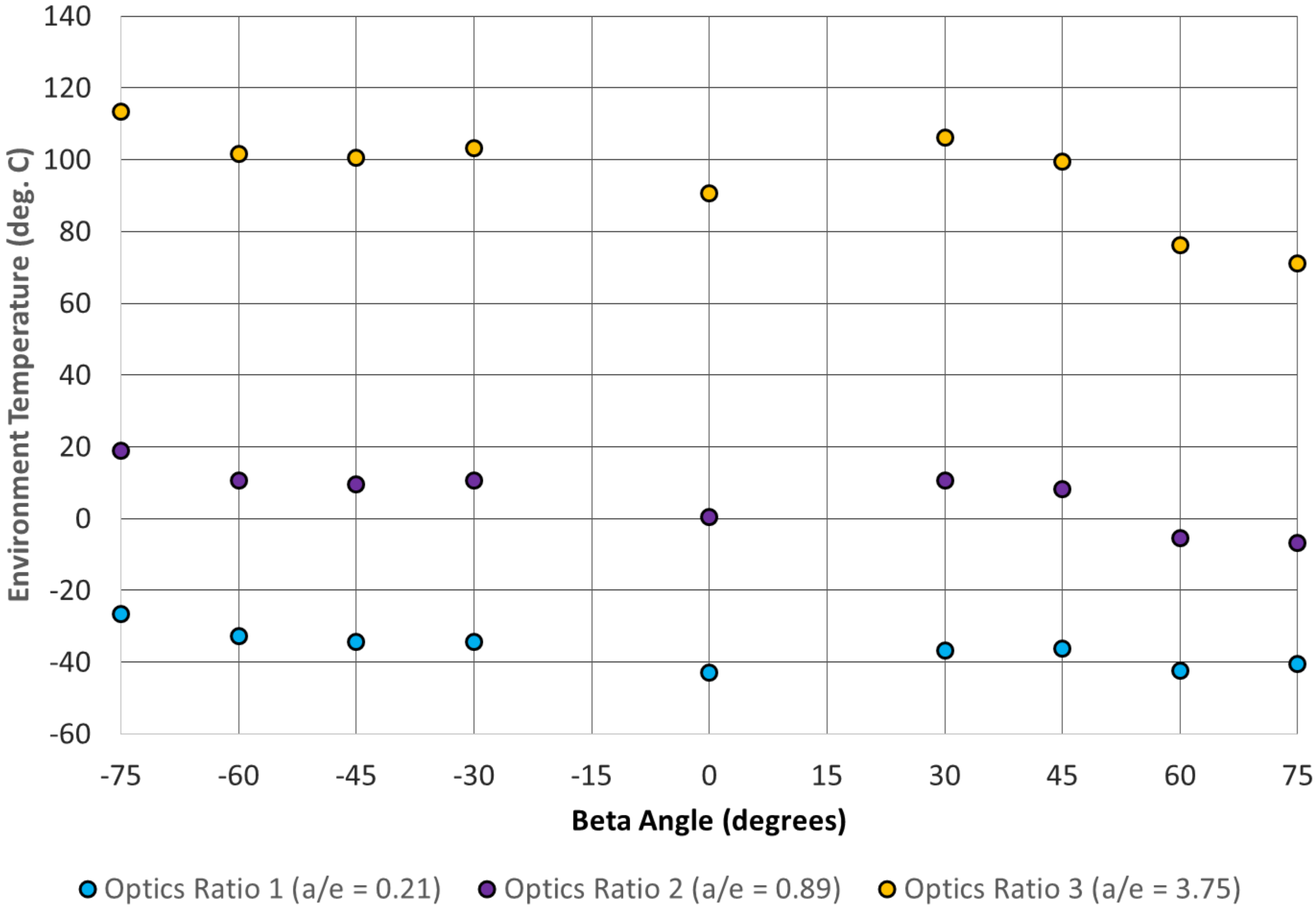
Location	Optical Ratio 3(α/ε = 0.45/0.12 = 3.75)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper
314 (ELC Inboard)	-66	-58	18	162 *	3	119 *
316 (Zenith)	-88	-81	102	149 *	71	113 *
315 (ELC Outboard)	-69	-56	39	155 *	12	126 *

Note – Environment range listed is for trending purposes only and may be significantly different for an actual payload geometry/optics
*** indicates temperature exceeds EVA incidental touch limit (+112.8 C)**

- Tables show how payload environment can vary with solar beta angle as well as optical property ratio
- Night pass range is similar to ELC-2, but much cooler than ELC-1
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C)

Representative ISS Environments

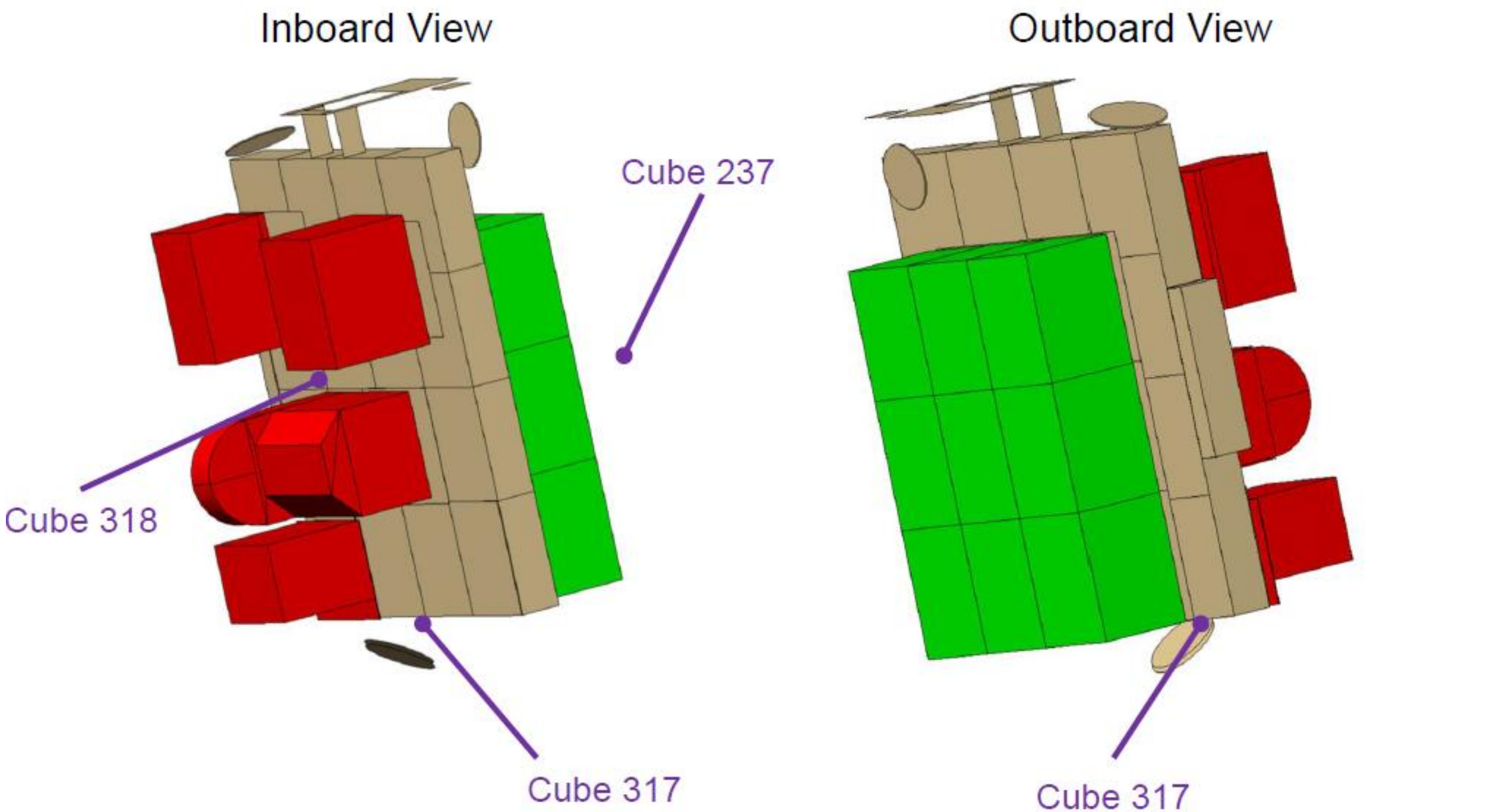
ELC-3 (Cube 316) Orbit Environment vs. Solar Beta for +XVV YPR = (-4°, -2°, +1°)



- Optical Property Ratio 1 ≤ -20° C for across the entire solar beta range.

Representative ISS Environments

ELC-4 Geometry (Nadir, Starboard)



Note – payload/ORU configuration can vary between inboard and outboard sides

Representative ISS Environments

ELC-4 Environment Summary Tables for +XVV YPR = (-4°, -2°, +1°)

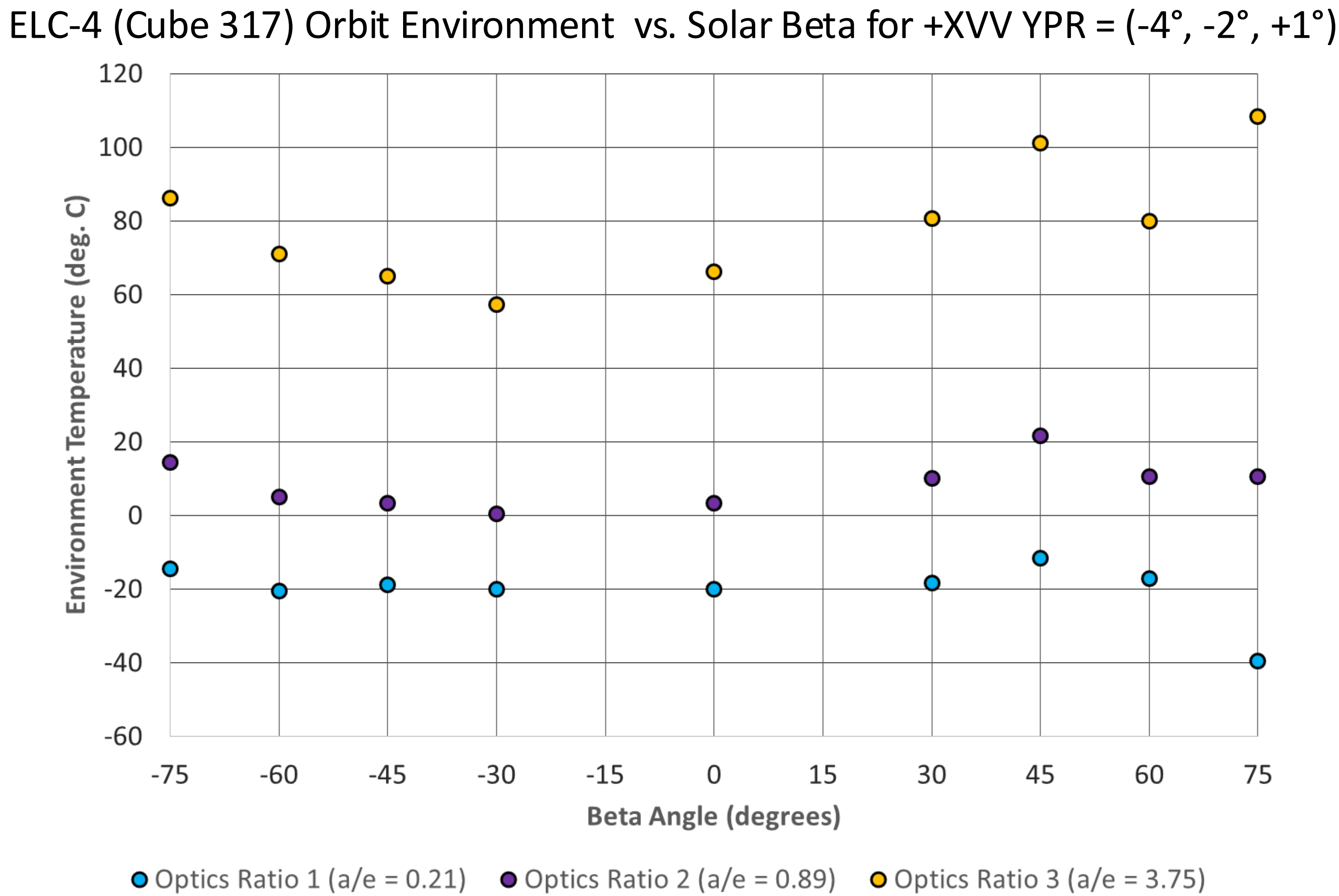
Location	Optical Ratio 1(α/ε = 0.18/0.84 = 0.21)						Optical Ratio 2(α/ε = 0.66/0.74 = 0.89)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)		Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
318 (ELC Inboard)	-47	-44	-34	-2	-34	-8	-47	-44	-20	38	-27	28
317 (Nadir)	-37	-35	-15	-2	-39	-12	-37	-35	16	40	1	22
327 (ELC Outboard)	-38	-27	-20	-1	-28	-7	-38	-27	-7	31	-21	12

Location	Optical Ratio 3(α/ε = 0.45/0.12 = 3.75)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper
318 (ELC Inboard)	-47	-44	15	130 *	-3	111
317 (Nadir)	-37	-35	87	134 *	57	108
327 (ELC Outboard)	-38	-27	33	118 *	4	79

Note – Environment range listed is for trending purposes only and may be significantly different for an actual payload geometry/optics
*** indicates temperature exceeds EVA incidental touch limit (+112.8 C)**

- Tables show how payload environment can vary with solar beta angle as well as optical property ratio
- ELC-4 results similar to ELC-1 and much warmer than ELC-2 or ELC-3
- Optical Ratio 3 data has only Day Pass violations of EVA incidental upper temperature (+112.8° C)

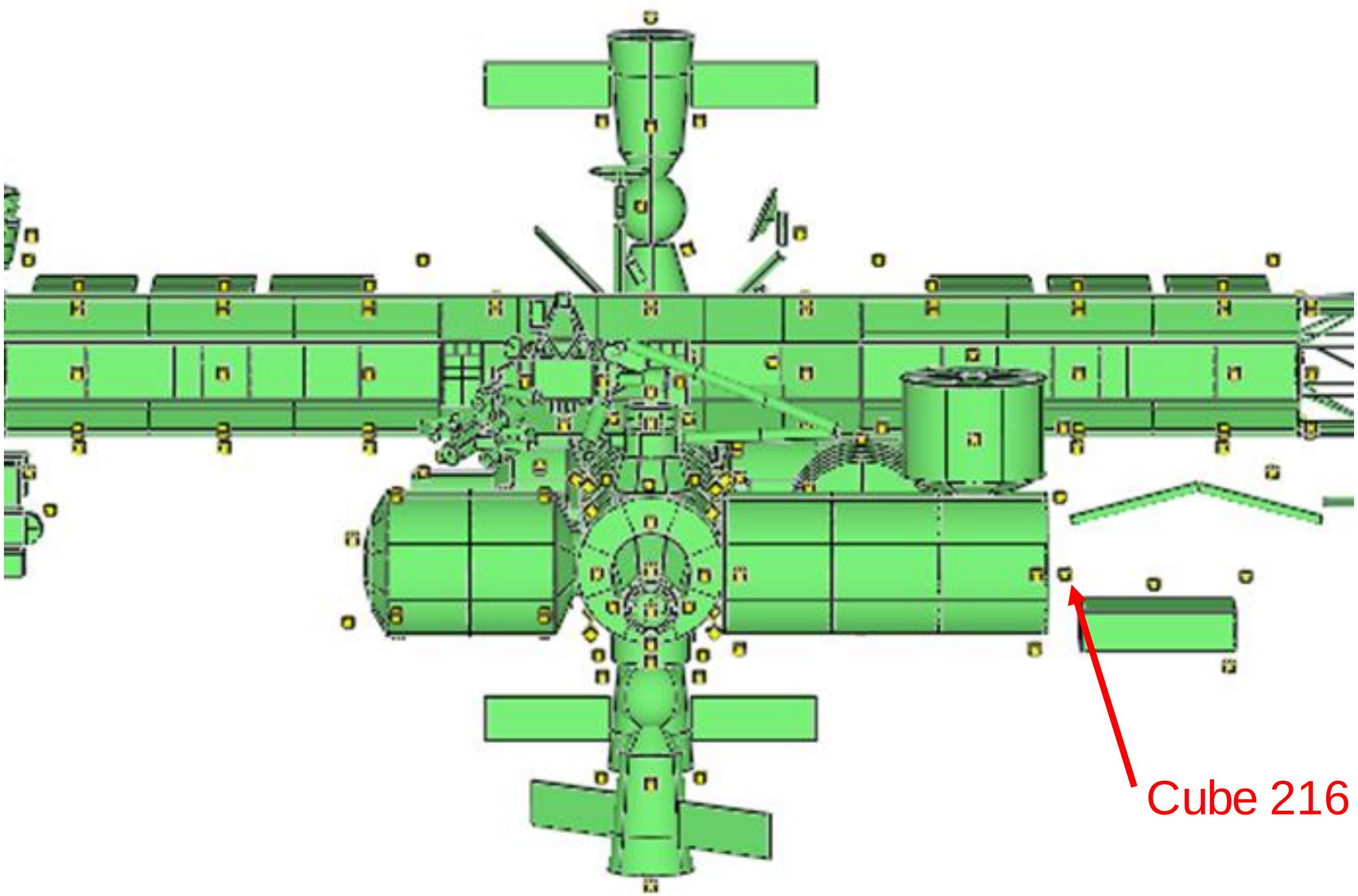
Representative ISS Environments



- Optical Property Ratio 1 is between -10° C and -40° C across solar beta range.

Representative ISS Environments

JEMAL Outer Hatch



Representative ISS Environments

JEMAL Environment Summary Tables for +XVV YPR = (-4°, -2°, +1°)

Location	Optical Ratio 1(α/ε = 0.18/0.84 = 0.21)						Optical Ratio 2(α/ε = 0.66/0.74 = 0.89)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)		Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
216 (JEMAL Hatch)	-65	-46	-43	14	-48	-2	-65	-46	-33	57	-40	31

Location	Optical Ratio 3(α/ε = 0.45/0.12 = 3.75)					
	Night (deg. C)		Day (deg. C)		Orbit (deg. C)	
	Lower	Upper	Lower	Upper	Lower	Upper
216 (JEMAL Hatch)	-65	-46	-3	156 *	-15	115 *

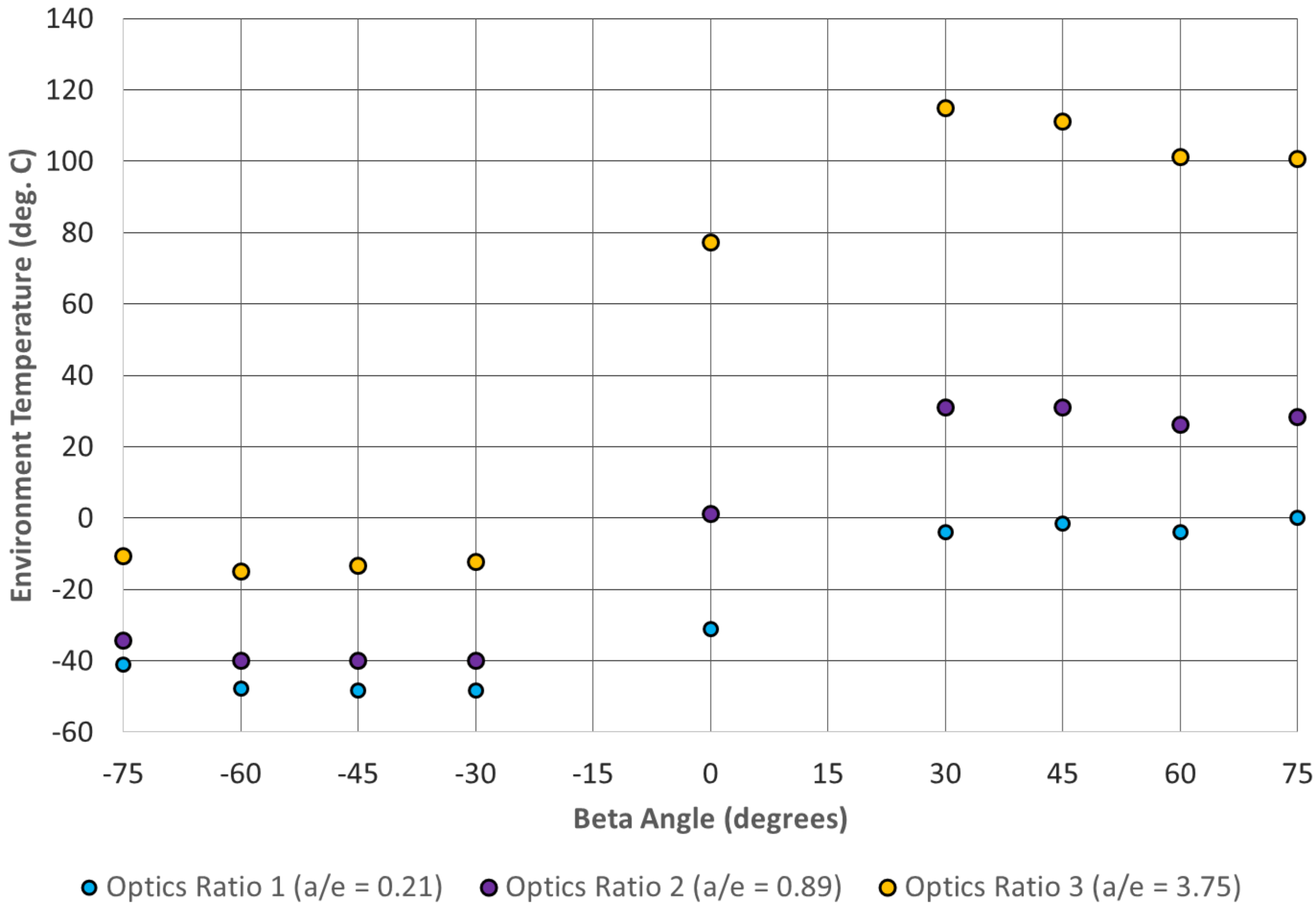
Note – Environment range listed is for trending purposes only and may be significantly different for an actual payload geometry/optics

*** indicates temperature exceeds EVA incidental touch limit (+112.8 C)**

- Tables show how payload environment can vary with solar beta angle as well as optical property ratio
- For cube 216 multiple solar beta angles (-30°, -45°, -60°, -75°) produce similar lower environment range values (see next slide)
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C)

Representative ISS Environments

JEMAL (Cube 216) Orbit Environment vs. Solar Beta for +XVV YPR = (-4°, -2°, +1°)



- For both Optical Property Ratios 1 & 2 the temperature is between -30° C and -50° C for solar betas < 0°.

Representative ISS Environments

Example of Expanded Cube Summary Table Data is for Cube 216

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	0	N/A	N/A	28	N/A	N/A	101
+60	-47	7	-4	-47	42	26	-47	126	101
+45	-47	**14 (U)**	**-2 (U)**	-47	53	**31 (U)**	-47	146	111
+30	**-46 (U)**	13	-4	**-46 (U)**	**57 (U)**	**31 (U)**	-46 (U)	**156 (U)**	**115 (U)**
0	-63	-17	-31	-63	26	1	-63	118	77
-30	**-65 (L)**	-40	**-48 (L)**	**-65 (L)**	-28	**-40 (L)**	**-65 (L)**	8	-12
-45	-64	-42	**-48 (L)**	-64	-31	**-40 (L)**	-64	3	-13
-60	-63	**-43 (L)**	**-48 (L)**	-63	**-33 (L)**	**-40 (L)**	-63	**-3 (L)**	**-15 (L)**
-75	N/A	N/A	-41	N/A	N/A	-34	N/A	N/A	-11

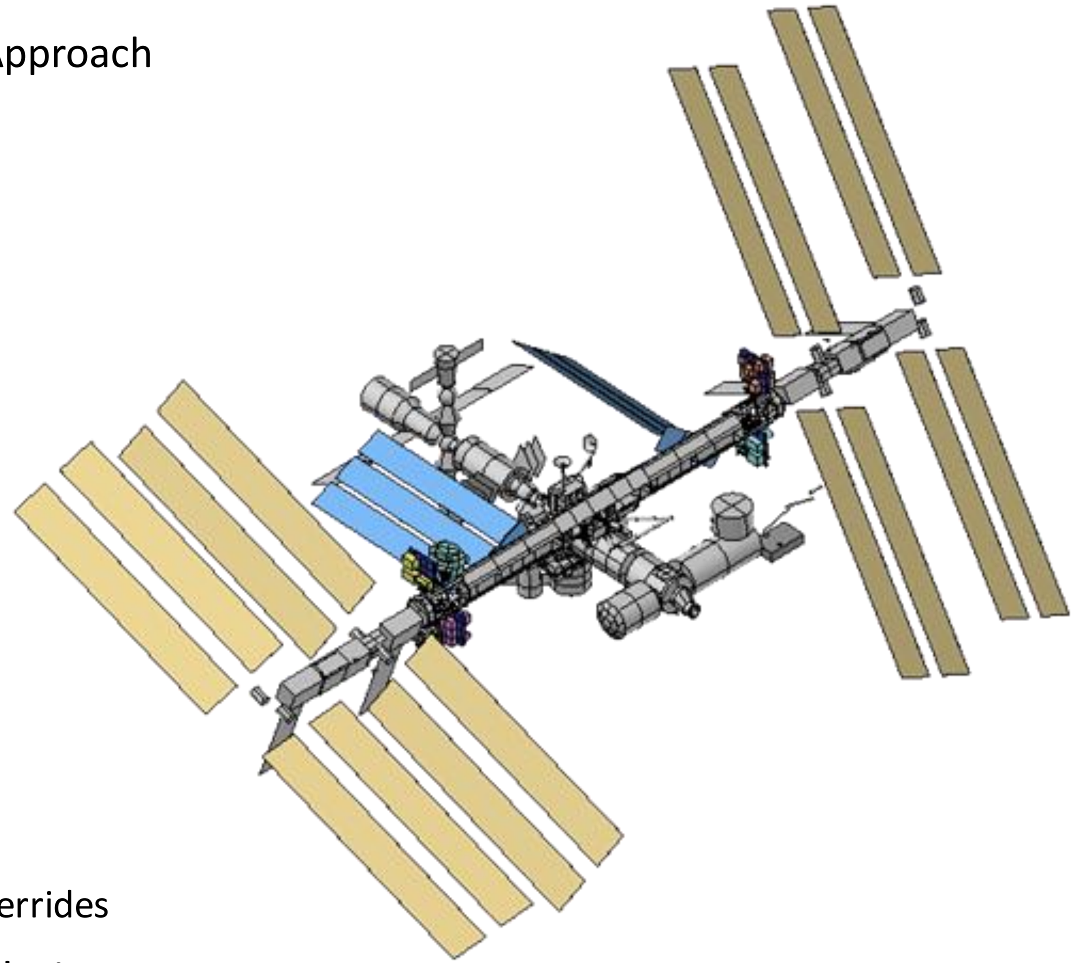
- For columns 2-10 the maximum temperature is in red text and includes “(U)” designation, while the minimum temperature is in purple text and includes “(L)”
- The table lists data for three optical property ratios with each optical property section designated with background colors of orange, white, & blue
  - Each column within an optical ratio section represents time average results for 30 minutes (night pass), 60 minutes (day pass) and 90 minutes (orbit).
- Temperatures above +112.8° C will result in EVA touch temperature violations
- Expanded tables for the other cubes can be found in Section 5 Appendix

6. ISS Reduced Fidelity Model

Caryn Preston

ISS Reduced Fidelity ("Simplified") Model

- Introduction
  - General Information and Approach
  - Model Organization
- Model Details
  - Coordinate System
  - Radiation Analysis Groups
  - Visiting Vehicles
  - Symbols
  - Articulators/Trackers
  - Pre-defined Sample Orbit
  - Orbit Animation
  - Case Set Manager
    - SINDA Build Statement
    - Symbol and Property Overrides
- Model Setup for Payload Analysis



ISS Simplified Model – Introduction

General Information and Approach

- Model is intended for use by hardware developers to determine the induced thermal environment imposed by the ISS
  - Available in Thermal Desktop (TD) and TRASYS/SINDA (T/S) formats; this presentation focuses on the TD version
    - Latest ISS model is V7R1, Documentation EID684-14800 rev B (Nov. 2014)
    - Model and documentation are available in EDMS
  - V7R1 is the only model version containing ISS-Assembly changes baselined in 2014
    - Two existing modules relocated
    - New U.S. docking port hardware added
    - New Russian hardware added
    - ELC payload complements updated
- V7R1 is the only model version with symbol-driven articulation of the ISS Arrays and Radiators, with angles consistent with on-orbit telemetry (operations)

ISS Simplified Model – Introduction

General Information and Approach

- Model has flexibility to simulate key operational aspects of ISS
  - Configurable for different stages of ISS assembly
  - Visiting Vehicles may be added at primary or alternate docking ports
    - Visiting Vehicles typically remain on ISS for 30-60 days
    - For most of the year, both Russian Nadir docking ports are occupied with Soyuz vehicles while a Progress vehicle is docked on the Zenith port
  - Independent control of ISS solar arrays and radiators, simulates theoretical tracking or parked operations
  - Pre-defined sample orbit may be used to simulate the three ISS flight attitudes recommended for payload thermal analysis: XVV, YVV, ZVV

ISS Simplified Model – Introduction

General Information and Approach - continued

- V7R1 incorporates many user-friendly features not available in earlier versions
  - Added TD symbols for defining orbital and environmental parameters, ISS array and radiator articulation, and ISS stage configurations
  - Improved model organization, reduced optical property file sizes and standardized property and layer names
  - Relocated all SINDA ("cond/cap") data from a sample Case Set to Logic Manager
  - Added additional sample cases, illustrating model setup for
    - Two ISS Stages (Increment 41 and Assembly Complete)
    - ISS flight attitudes (XVV, YVV, and ZVV)

ISS Simplified Model – Introduction

Model Organization

- Layers
  - All geometry is organized in layers with names beginning with "ISS_" for easy identification when integrated with other models
  - A separate layer called "ISS_Trackers" contains all articulators and trackers
- Optical Properties
  - Separate database files are provided for ISS Beginning-of-Life (BOL) and End-of-Life (EOL) optical properties
- Analysis Groups
  - Separate groups are pre-defined for
    - ISS Assembly Complete (~ 2020 configuration)
    - Increment 41 (Nov. 2014 configuration)
    - Visiting Vehicles (ATV, HTV, Orbital Cygnus, SpaceX Dragon, and Orion-Representative Future Vehicle)

ISS Simplified Model – Introduction

Model Organization - continued

- Symbols
  - All symbols are organized into Groups with names beginning with “ISS_”
  - Symbols are defined for environmental parameters, Beta Angle, ISS vehicle altitude and Yaw/Pitch/Roll, ISS Stage configuration, and US Operating Segment (USOS) solar array/radiator articulation control
- Articulators and Trackers
  - Articulators are set up to reposition geometry – Visiting Vehicles, also some ISS elements
  - Trackers are set up to rotate ISS solar arrays and radiators
- Sample Orbit
  - Sample orbit is set up, applicable for XVV, YVV and ZVV attitudes

ISS Simplified Model – Introduction

Model Organization - continued

- All SINDA data is located in Logic Manager
  - One Logic Block *per submodel* – all Node, Conductor, Array, Variables blocks are contained in one block per submodel, under a NODE DATA heading
  - The user does not need to alter these Logic Blocks
- User-Defined SINDA Build Card
  - User selects which submodels to build/not build
  - Allows flexibility to model any ISS stage configuration
- SINDA submodel naming convention
  - All SINDA submodel names begin with “S”, except Grapple Fixture names begin with “GF”

ISS Simplified Model – Introduction

Model Organization - continued

- “Post-IDA Install” configuration, a hybrid of Increment 41 and Assembly Complete, will be pre-defined in upcoming model release V7R2
  - Post-IDA Install is the recommended configuration for payload analyses for the next several years, based on the ISS Flight Plan (In-Work), Updated July 1, 2015
  - Flight Plan is continually In-Work, may change!
  - Russian module additions are planned for ~ mid-2017 until ~ 2020 (no earlier than)
    - MLM and RS-Node installation ~ 2017; SPM installation ~ 2020
- Model units are English [Btu-hr-lbm-ft-F]
  - ISS model units cannot be changed on the TD “Thermal -> Preferences -> Units” Tab
    - Units settings on this Tab do not modify the hard-coded SINDA data in the Logic Blocks
- An SI version of the ISS model is planned for release with V7R2

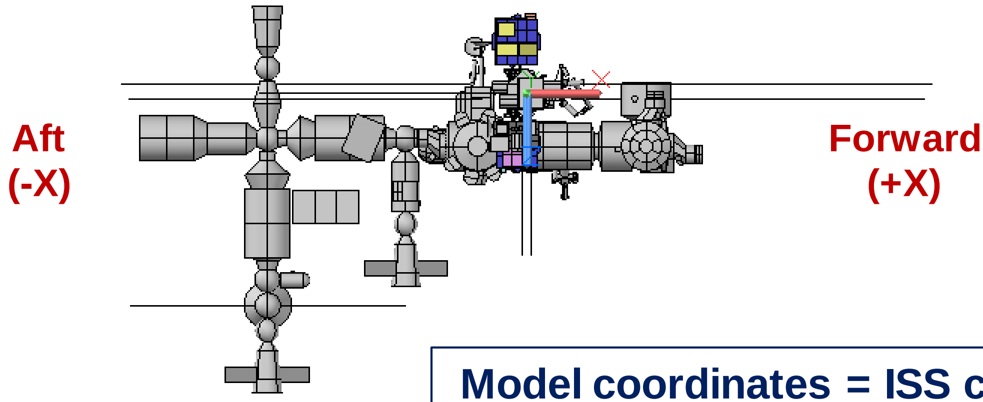
ISS Simplified Model – Introduction

Model Organization - continued

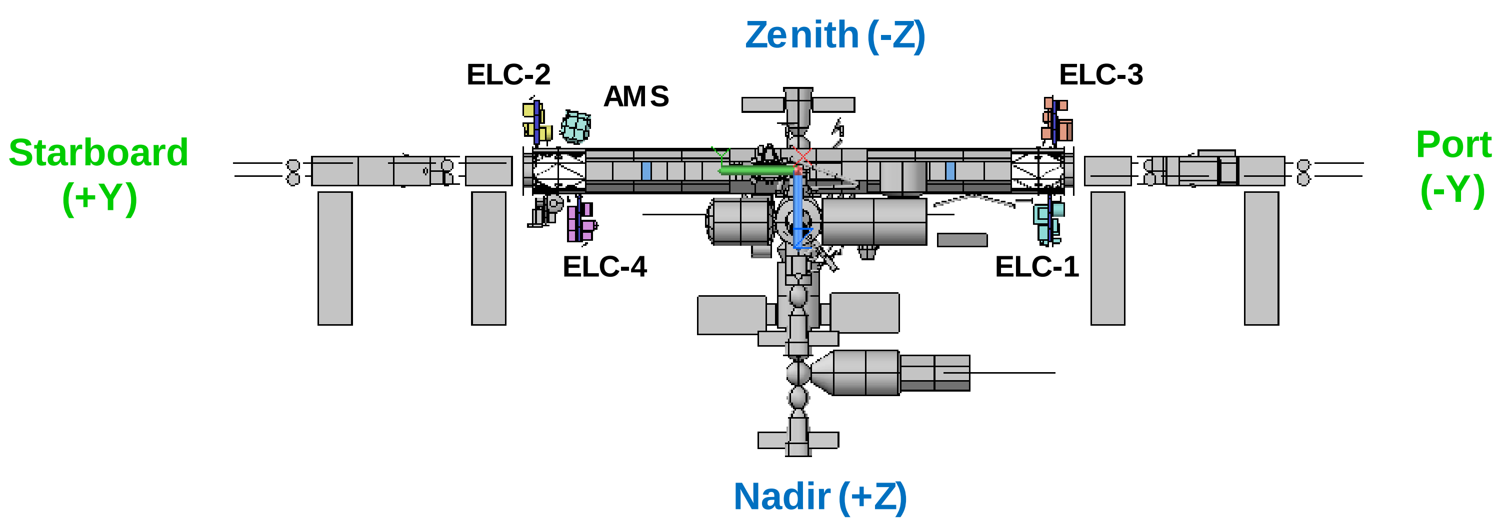
- The TD model was imported from a traditional TRASYS/SINDA model, therefore it has these features:
  - All geometry represents external surfaces; the TD "insulation" Tab is not used
  - There is no material property file, *no SINDA data is auto-generated by TD!*
  - All geometry is 2-D, no solids
  - Node correspondence is used (Thermal -> Modeling Tools -> Node Correspondence), allows multiple surfaces to be assigned to a single SINDA node
  - Many features familiar to TD users are not used, such as Domain Tag Sets, Aliases, TD Heaters, Heat Loads, Contactors, Conductors, etc.

ISS Simplified Model – Coordinate System

Assembly Complete configuration shown



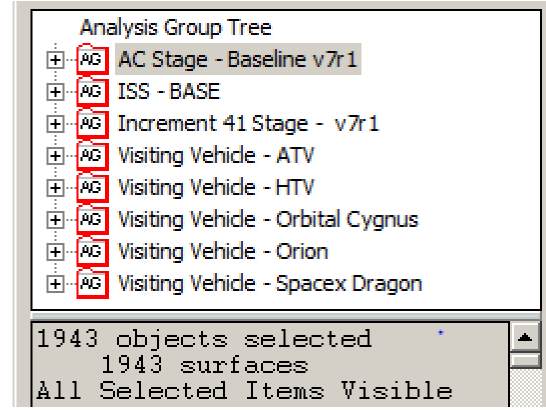
Model coordinates = ISS coordinates



ISS Simplified Model – Radiation Analysis Groups

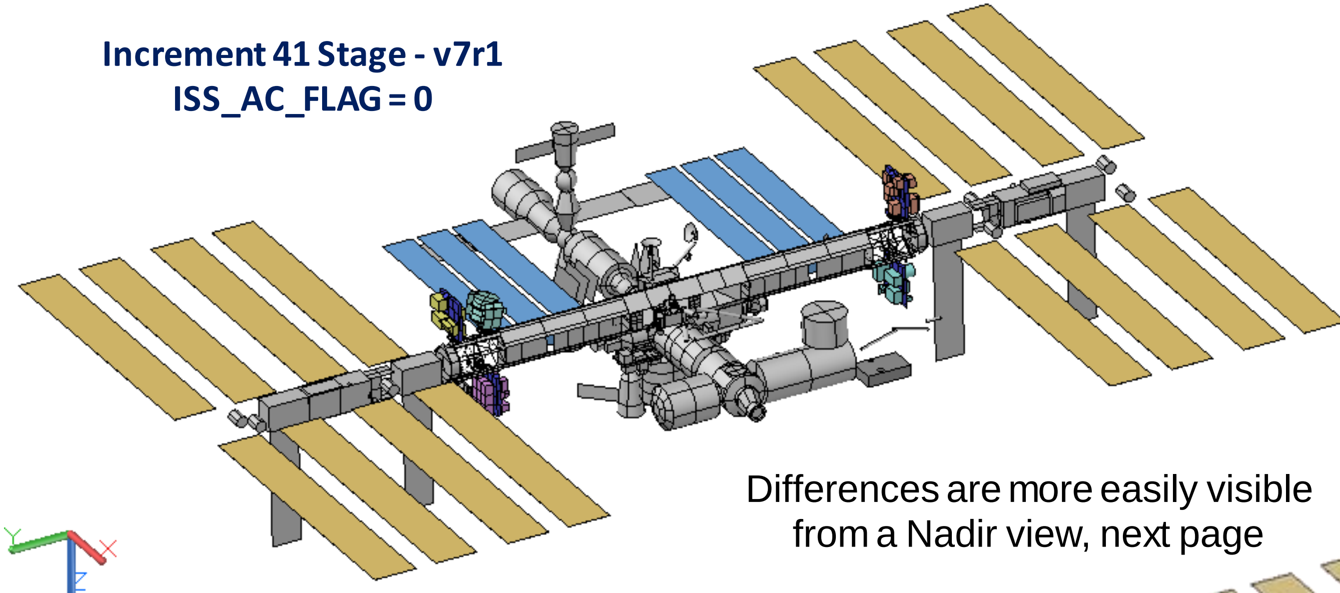
- Pre-defined Analysis Groups and symbol ISS_AC_FLAG are intended to be used together
  - Group “Increment 41 Stage – v7r1” with ISS_AC_FLAG = 0 represents the ISS as of November 2014
  - Group “AC Stage – Baseline v7r1” with ISS_AC_FLAG = 1 represents Assembly Complete
- Group “ISS – BASE” contains all geometry
  - *Does not represent any real ISS configuration, should never be used for analysis*
- Individual groups are pre-defined for each ISS Visiting Vehicle
  - ATV, HTV, Orbital Cygnus, Orion (represents a future vehicle), and SpaceX Dragon
- Russian Visiting Vehicle assumption
  - Two Soyuz vehicles docked to Russian Nadir ports
  - One Progress vehicle docked to a Russian Zenith Port

Model Browser/ List by Analysis Group

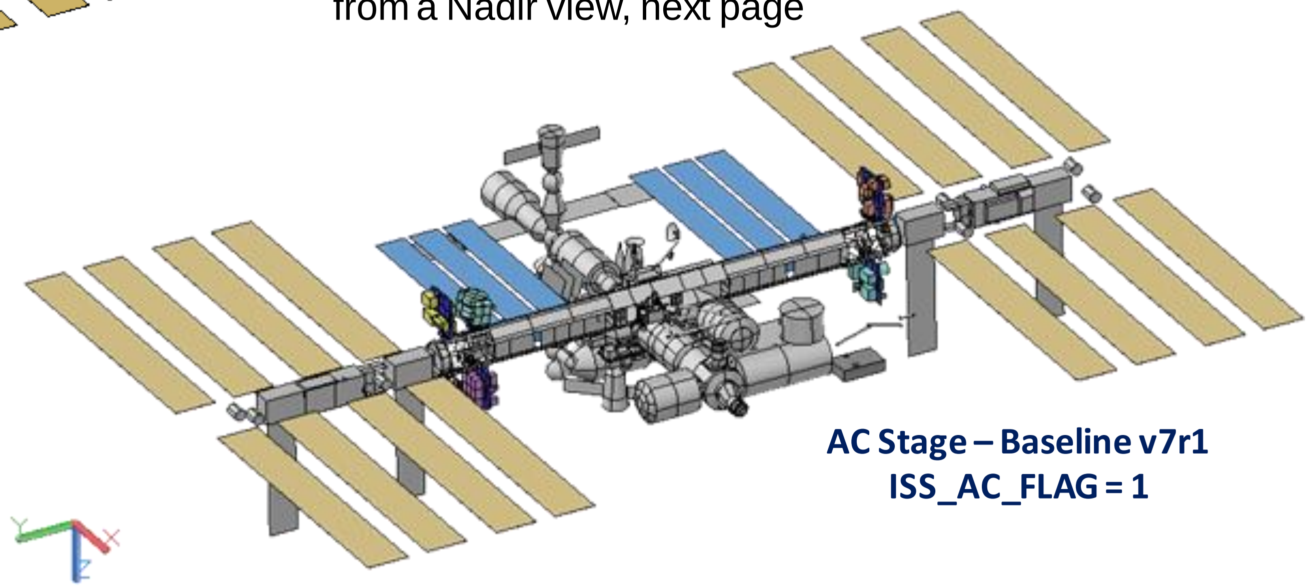


ISS Simplified Model – Radiation Analysis Groups

Increment 41 Stage - v7r1
ISS_AC_FLAG = 0



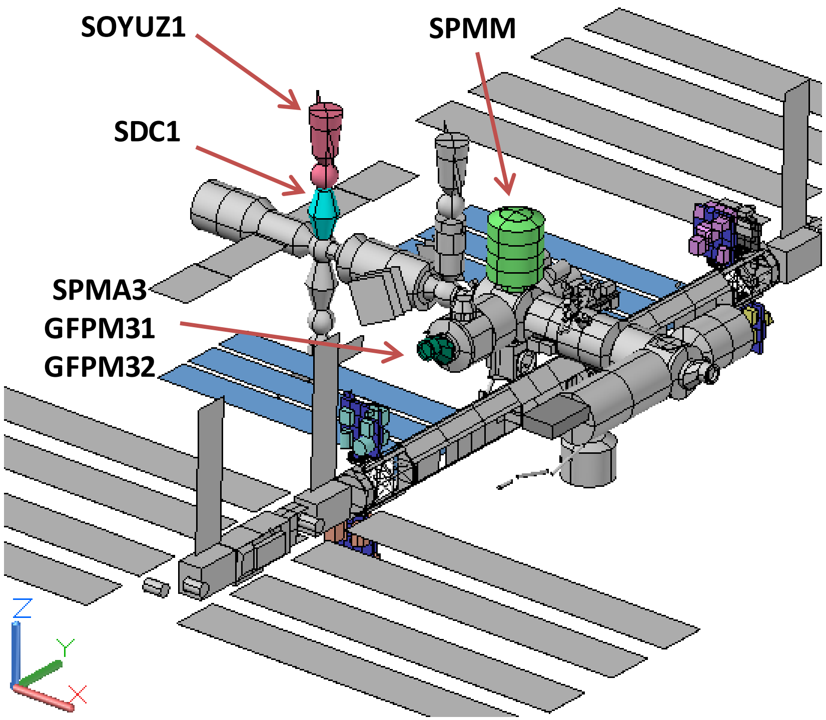
Differences are more easily visible from a Nadir view, next page



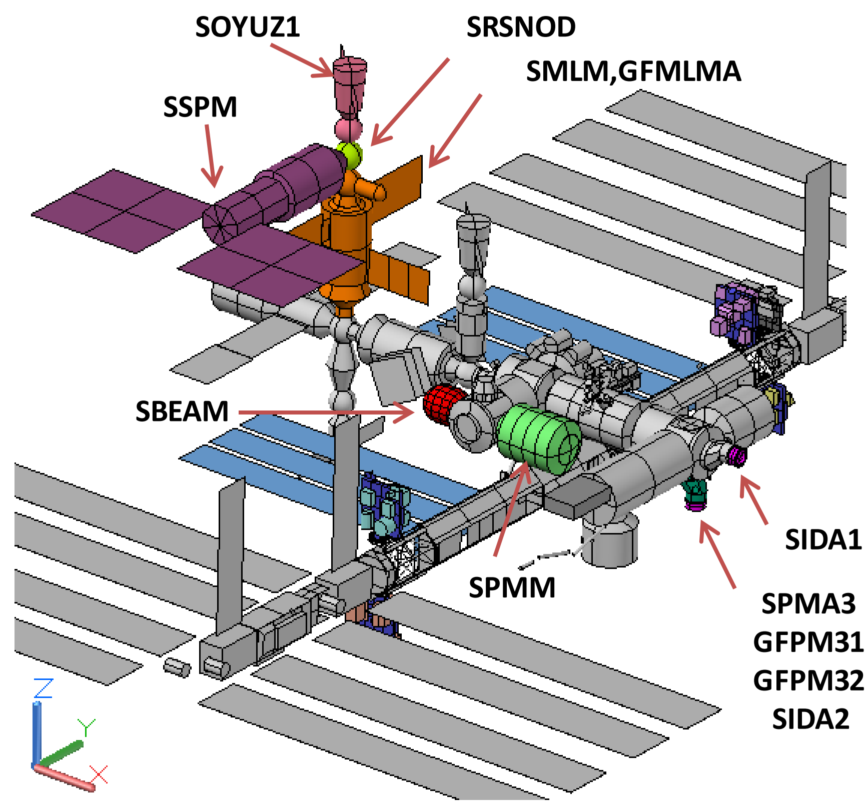
AC Stage – Baseline v7r1
ISS_AC_FLAG = 1

ISS Simplified Model – Radiation Analysis Groups

Increment 41 Stage – v7r1
ISS_AC_FLAG = 0



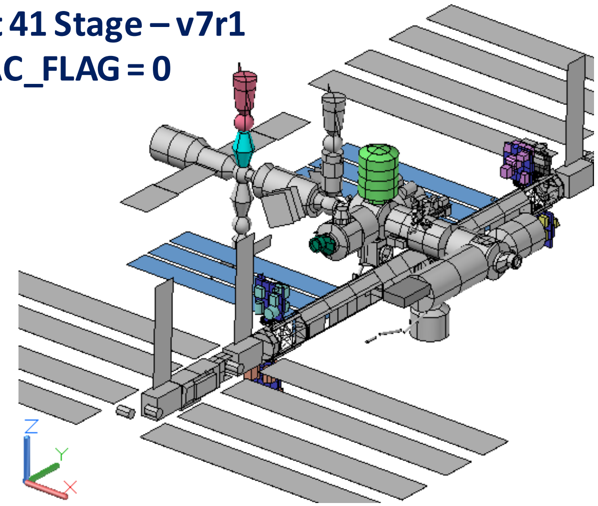
AC Stage Baseline – v7r1
ISS_AC_FLAG = 1



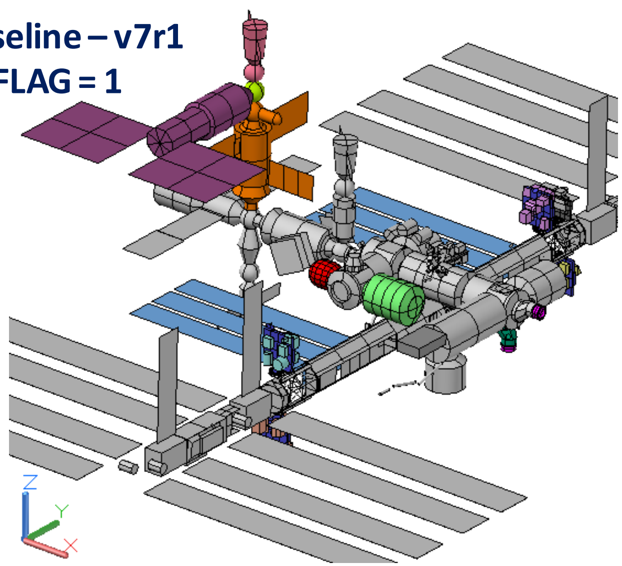
Submodel names are shown

ISS Simplified Model – Radiation Analysis Groups

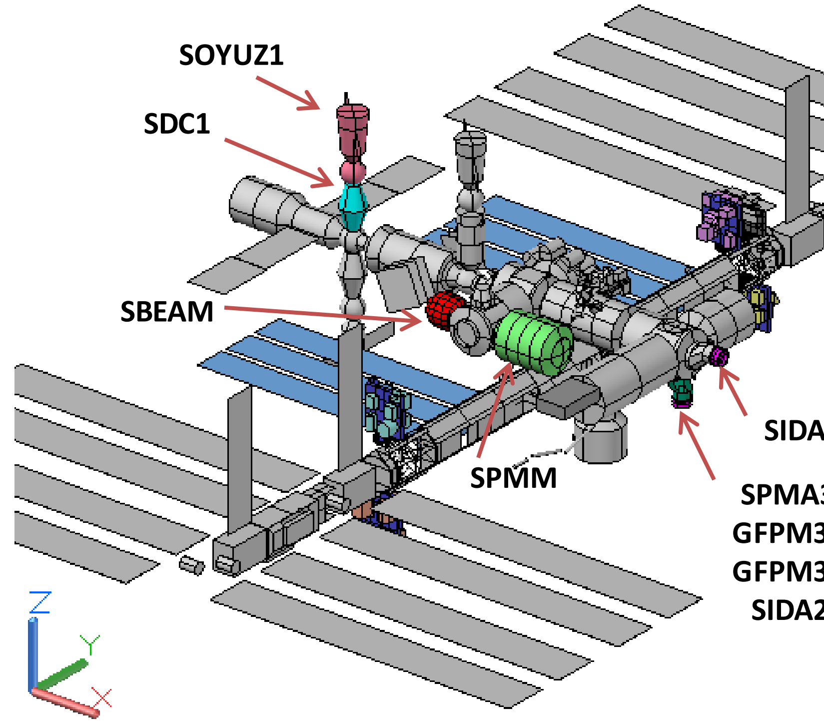
Increment 41 Stage – v7r1
ISS_AC_FLAG = 0



AC Stage Baseline – v7r1
ISS_AC_FLAG = 1



Post-IDA-Install
(hybrid configuration, available in V7R2)
ISS_AC_FLAG = 1



Submodel names are shown

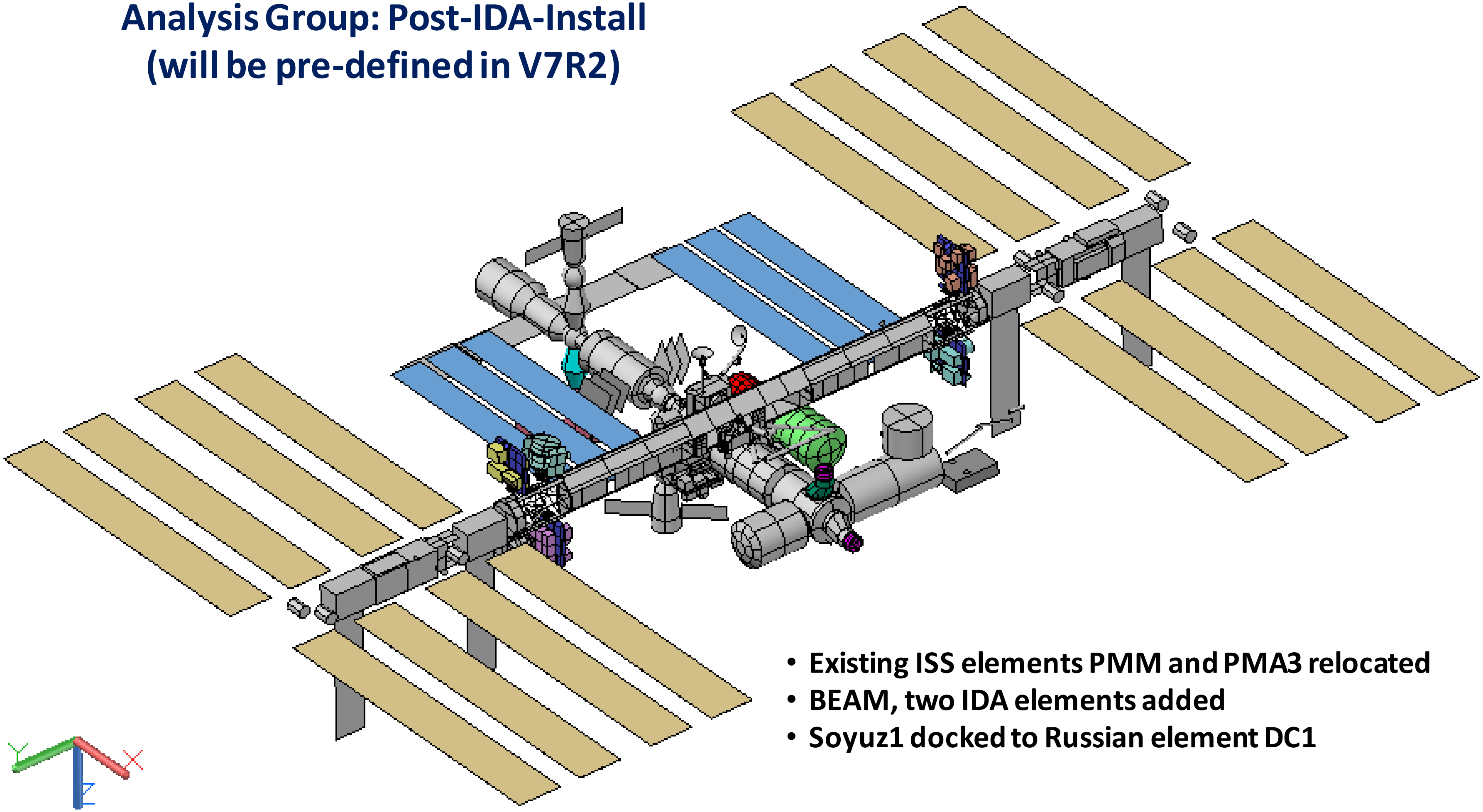
Existing ISS elements PMM and PMA3 relocated
- PMM = Permanent Multi-Purpose Module
- PMA3 = Pressurized Mating Adapter-3

BEAM, two IDA elements added

Soyuz1 docked to Russian element DC1

ISS Simplified Model – Radiation Analysis Groups

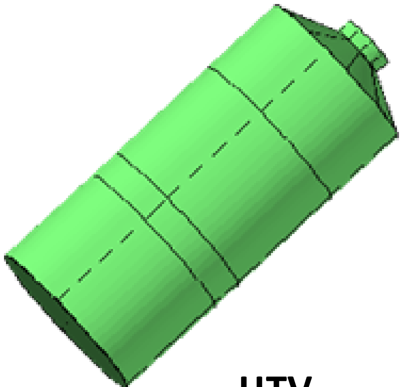
Analysis Group: Post-IDA-Install (will be pre-defined in V7R2)



- Existing ISS elements PMM and PMA3 relocated
- BEAM, two IDA elements added
- Soyuz1 docked to Russian element DC1

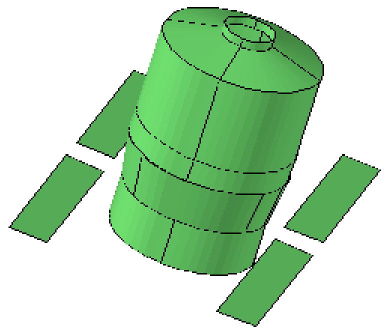
ISS Simplified Model – Radiation Analysis Groups

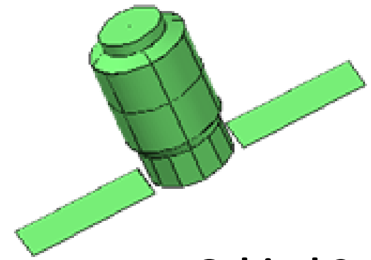
Visiting Vehicle Analysis Groups



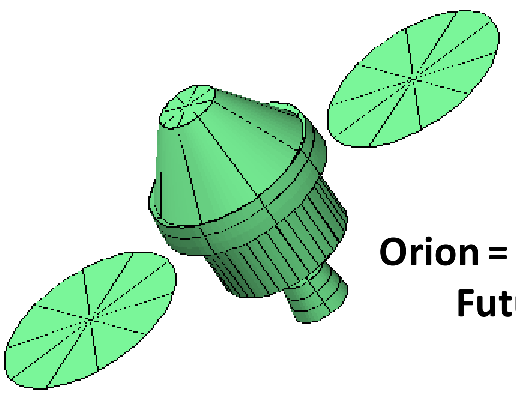
HTV

ATV



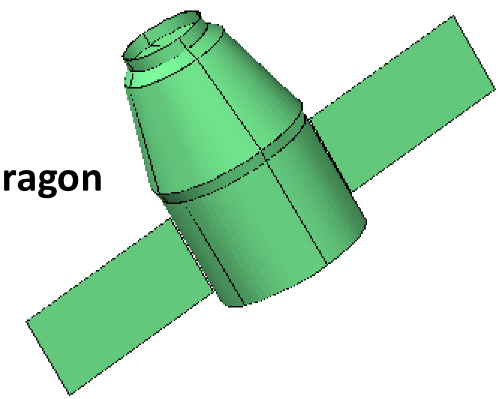


Orbital Cygnus



Orion = Representative Future Vehicle

SpaceX Dragon



ISS Simplified Model – Visiting Vehicles

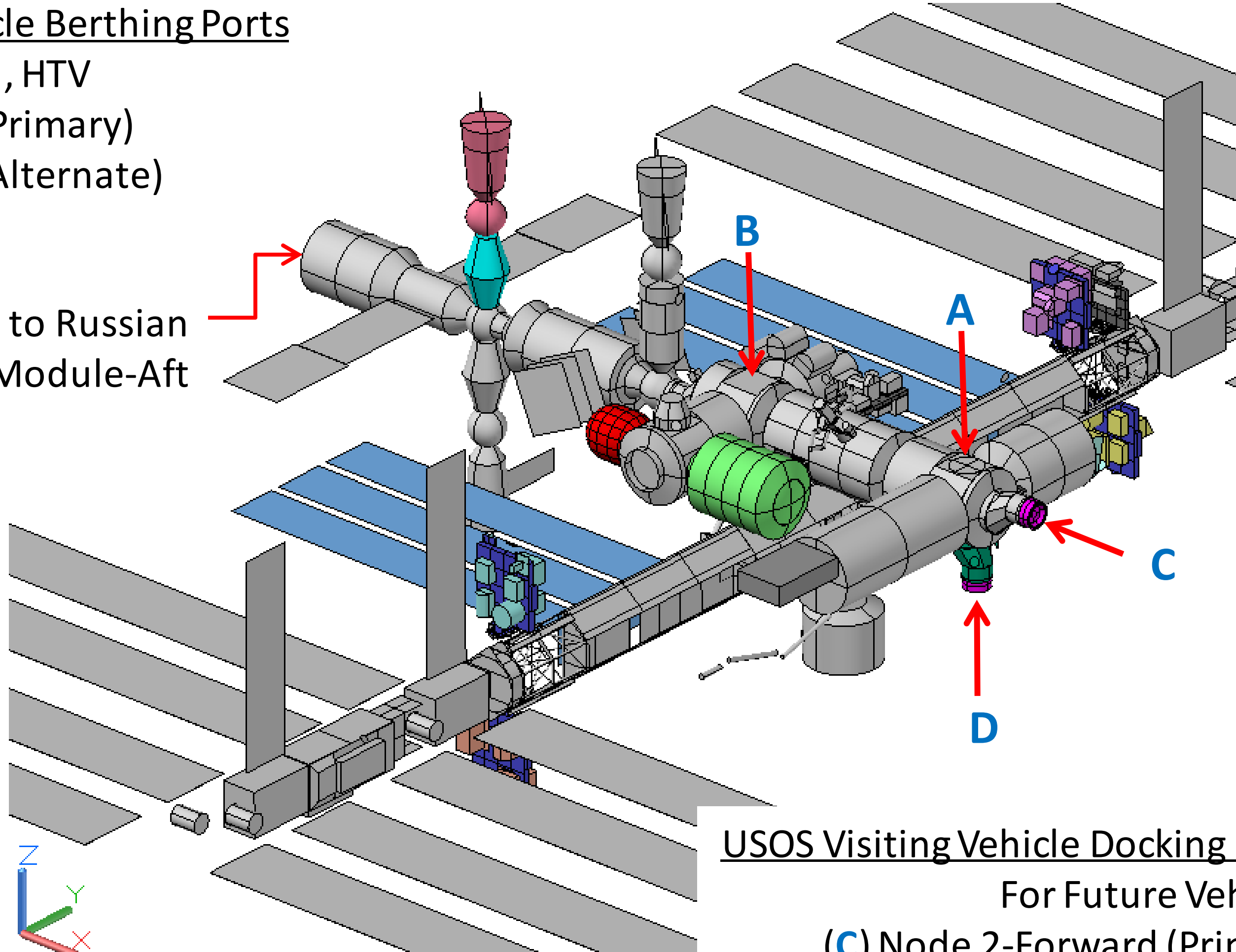
USOS Visiting Vehicle Berthing Ports

For SpaceX, Orbital, HTV

(**A**) Node 2-Nadir (Primary)

(**B**) Node 1-Nadir (Alternate)

ATV – docks to Russian
Service Module-Aft



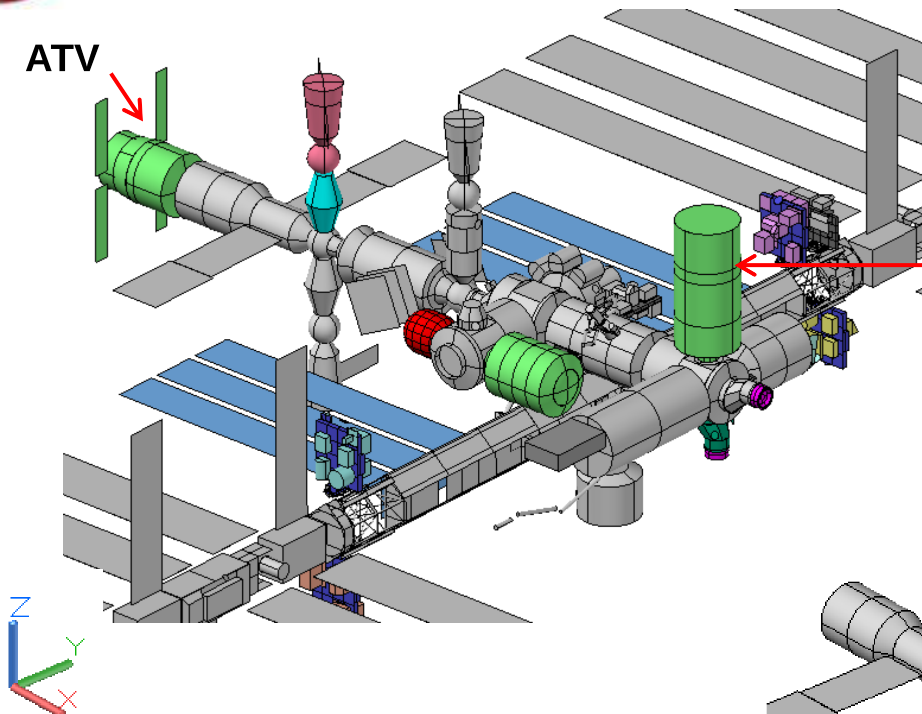
USOS Visiting Vehicle Docking Ports

For Future Vehicles

(**C**) Node 2-Forward (Primary)

(**D**) Node 2-Zenith (Alternate)

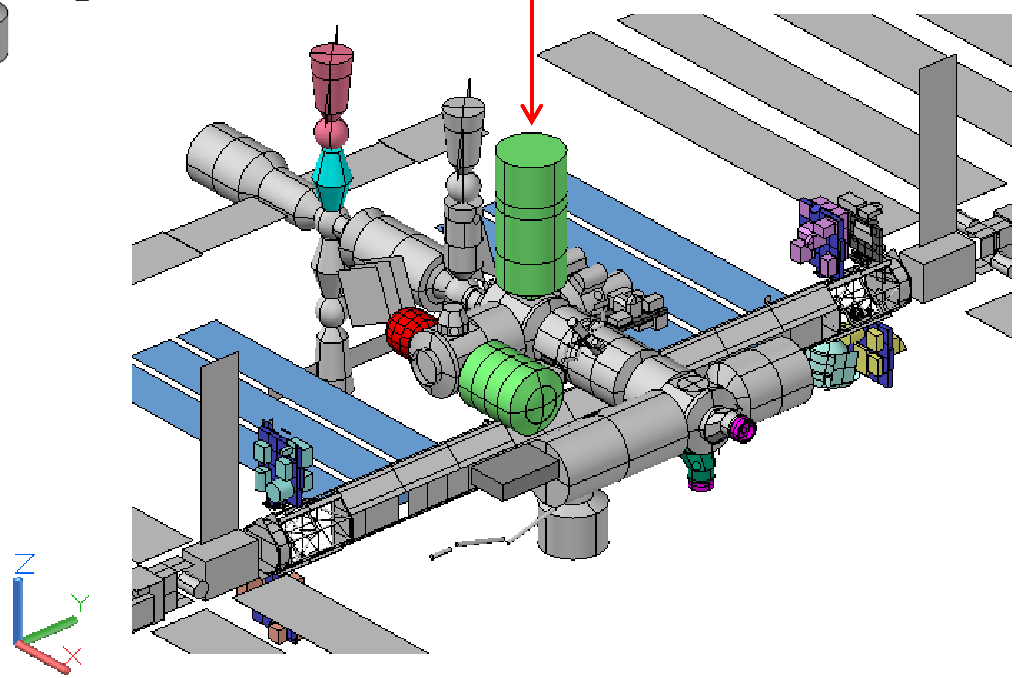
ISS Simplified Model – Visiting Vehicles



Example of Visiting Vehicles at ISS

HTV at Primary Docking Port – Node 2 Nadir

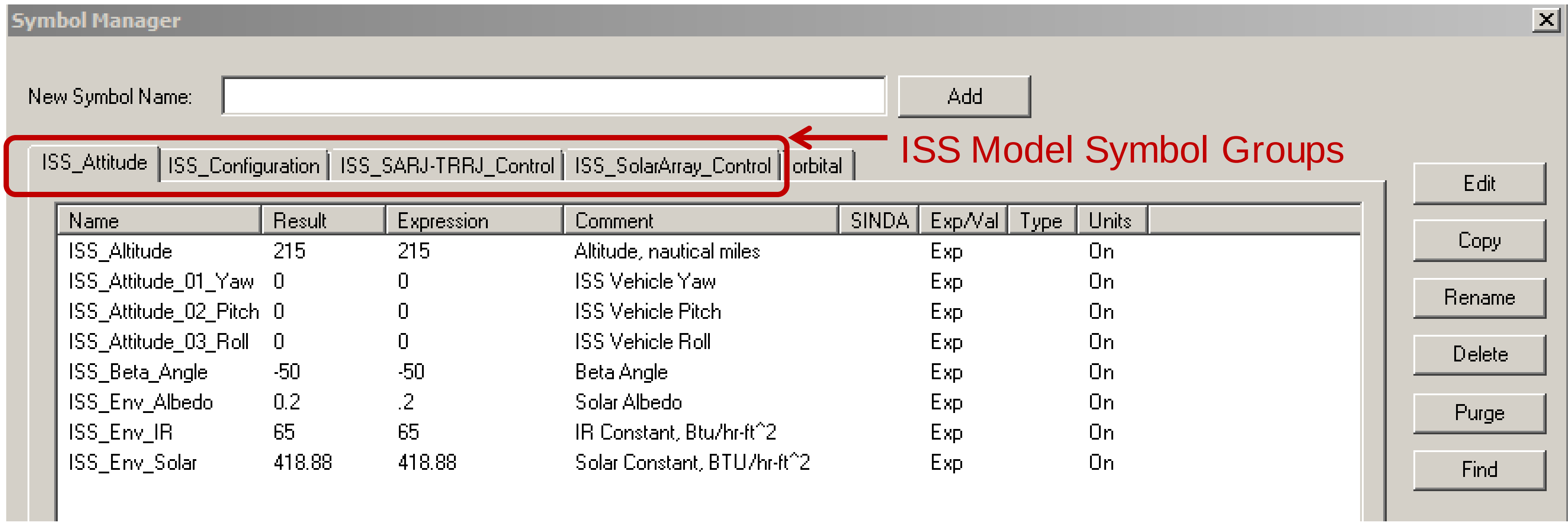
HTV at Secondary Docking Port – Node 1 Nadir



Visiting Vehicles are typically at ISS for 30-60 day durations; their presence can influence the overall ISS thermal environment

ISS Simplified Model – Symbols

- Symbols are organized into Groups, accessible through Symbol Manager
  - ISS Model Symbol Group names begin with “ISS_”
  - TD Auto-Generated Symbols are in Group “orbital”



Name	Result	Expression	Comment	SINDA	Exp/Val	Type	Units
ISS_Altitude	215	215	Altitude, nautical miles		Exp		On
ISS_Attitude_01_Yaw	0	0	ISS Vehicle Yaw		Exp		On
ISS_Attitude_02_Pitch	0	0	ISS Vehicle Pitch		Exp		On
ISS_Attitude_03_Roll	0	0	ISS Vehicle Roll		Exp		On
ISS_Beta_Angle	-50	-50	Beta Angle		Exp		On
ISS_Env_Albedo	0.2	.2	Solar Albedo		Exp		On
ISS_Env_IR	65	65	IR Constant, Btu/hr-ft^2		Exp		On
ISS_Env_Solar	418.88	418.88	Solar Constant, BTU/hr-ft^2		Exp		On

- It is important to note that orbit visualizations will be based on Global symbols as defined in Symbol Manager, regardless of Symbol Overrides in a Case Set

ISS Simplified Model – Symbols

ISS Configuration and Attitude Symbol Groups

Group	Symbol	Description	Units	Values
ISS_Configuration [note 1]	ISS_AC_Flag	Control Flag for ISS Configuration - use in combination with appropriate Radiation Analysis Group	n/a	0 = Increment 41 1 = Assembly Complete
	IHEATS	Conrol Flag for SINDA boundary conditions and heat loads	n/a	0 = cold-biased 1 = average of hot and cold 2 = nominal hot 3 = extreme hot
ISS_Attitude [note 2]	ISS_Altitude	Orbit Altitude	naut. miles	Refer to JSC-66617 for guidance on ISS vehicle attitude and natural environment analysis parameters
	ISS_Attitude_01_Yaw	ISS Vehicle Yaw	degrees	
	ISS_Attitude_02_Pitch	ISS Vehicle Pitch	degrees	
	ISS_Attitude_03_Roll	ISS Vehicle Roll	degrees	
	ISS_Beta_Angle	Solar Beta Angle	degrees	
	ISS_Env_Albedo	Albedo	n/a	
	ISS_Env_IR	Earth IR	Btu/hr-ft2	
	ISS_Env_Solar	Solar Constant	Btu/hr-ft2	

[1] Use ISS_AC_Flag = 0 in combination with Radiation Analysis Group “Increment 41 Stage – v7r1”
Use ISS_AC_Flag = 1 in combination with Radiation Analysis Group “AC Stage – Baseline v7r1”

[2] For XVV, YVV, or ZVV orbits, the Orbit “Orientation” is defined as +Z-Nadir, with Yaw/Pitch/Roll entered in the “Additional Rotations” fields in the order Z/Y/X

ISS Simplified Model – Symbols

ISS Articulation Control Groups

Group	Symbol	Description	Units	Values
ISS_SARJ_TRRJ_Control [note 3]	ISS_Control_PSARJ	Control Flag for Port SARJ	n/a	0 = locked, 1 = rotating
	ISS_Control_PTRRJ	Control Flag for Port TRRJ	n/a	0 = locked, 1 = rotating
	ISS_Control_SSARJ	Control Flag for Starboard SARJ	n/a	0 = locked, 1 = rotating
	ISS_Control_STRRJ	Control Flag for Starboard TRRJ	n/a	0 = locked, 1 = rotating
	ISS_PSARJ	Port SARJ lock angle	degrees	0° to 360°
	ISS_PTRRJ	Port TRRJ lock angle	degrees	-105° to +105°
	ISS_SSARJ	Starboard SARJ lock angle	degrees	0° to 360°
	ISS_STRRJ	Starboard STRRJ lock angle	degrees	-105° to +105°
ISS_SolarArray_Control [note 3]	ISS_Control_P4_BETA2A	Control Flag for BGA P4_2A	n/a	0 = locked, 1 = rotating
	ISS_Control_P4_BETA4A	Control Flag for BGA P4_4A	n/a	0 = locked, 1 = rotating
	ISS_Control_P6_BETA2B	Control Flag for BGA P6_2B	n/a	0 = locked, 1 = rotating
	ISS_Control_P6_BETA4B	Control Flag for BGA P6_4B	n/a	0 = locked, 1 = rotating
	ISS_Control_S4_BETA1A	Control Flag for BGA S4_1A	n/a	0 = locked, 1 = rotating
	ISS_Control_S4_BETA3A	Control Flag for BGA S4_3A	n/a	0 = locked, 1 = rotating
	ISS_Control_S6_BETA1B	Control Flag for BGA S6_1B	n/a	0 = locked, 1 = rotating
	ISS_Control_S6_BETA3B	Control Flag for BGA S6_3B	n/a	0 = locked, 1 = rotating
	ISS_P4_BETA2A	BGA P4_2A lock angle	degrees	0° to 360°
	ISS_P4_BETA4A	BGA P4_4A lock angle	degrees	0° to 360°
	ISS_P6_BETA2B	BGA P6_2B lock angle	degrees	0° to 360°
	ISS_P6_BETA4B	BGA P6_4B lock angle	degrees	0° to 360°
	ISS_S4_BETA1A	BGA S4_1A lock angle	degrees	0° to 360°
	ISS_S4_BETA3A	BGA S4_3A lock angle	degrees	0° to 360°
	ISS_S6_BETA1B	BGA S6_1B lock angle	degrees	0° to 360°
	ISS_S6_BETA3B	BGA S6_3B lock angle	degrees	0° to 360°

Each Tracker is controlled by 2 symbols:

(1) A control flag, which determines if the tracker is rotating or locked

(2) A lock angle, applicable if the tracker is locked

[3] SARJ = Solar Array Rotary Joint; TRRJ = Thermal Radiator Rotary Joint; BGA =Beta Gimbal Assembly
The SARJ/TRRJ/BGA lock angles are entered in MOD-convention, consistent with on-orbit telemetry (see Table 7-1 of model documentation for cross-referenced list of telemetry names).

ISS Simplified Model – Articulators/Trackers

- Articulators are defined to re-position geometry; Trackers are defined to rotate geometry

Model Browser / List by Layer

- ISS_Trackers
  - Articulator-Detailed Port and Petals::3733
  - Articulator-HTV::1E59
  - Articulator-Orbital Cygnus::58BF
  - Articulator-Orion::57E7
  - Articulator-Progress::1E65
  - Articulator-SPMA3 and FRGFs::57C5
  - Articulator-SPMM::57C1
  - Articulator-Soyuz1::1E5A
  - Articulator-Soyuz2::1E64
  - Articulator-Spacex Dragon ::1E58
  - Tracker-P1 TRRJ Offset in Eclipse::1E1B
  - Tracker-P1 TRRJ::1E1A
  - Tracker-P3 SARJ::1DF4
  - Tracker-P4 - 2A, Aft - SP4W4B::1DF2
  - Tracker-P4 - 4A, Forward - SP4W2B::1DF0
  - Tracker-P6 - 2B, Forward - SPSW2B::1DF1
  - Tracker-P6 - 4B, Aft - SPSW4B::1DF3
  - Tracker-Russian MLM Arrays - SMLMW::1DFA
  - Tracker-Russian MLM Radiator - SMLMRD::1E19
  - Tracker-Russian MLM Radiator Offset in Eclipse::1E66
  - Tracker-Russian SM Arrays - SSMW2::1DF8
  - Tracker-Russian SPM PV Arrays::57D9
  - Tracker-S1 TRRJ Offset in Eclipse::1E26
  - Tracker-S1 TRRJ::1E25
  - Tracker-S3 SARJ::1DF6
  - Tracker-S4 - 1A, Forward - SS4W4B::1DED
  - Tracker-S4 - 3A, Aft - SS4W2B::1DDA
  - Tracker-S6 - 1B, Aft - SS6W2B::1DEF
  - Tracker-S6 - 3B, Forward - SS6W4B::1DEE

Model Browser / List by Articulators/Trackers

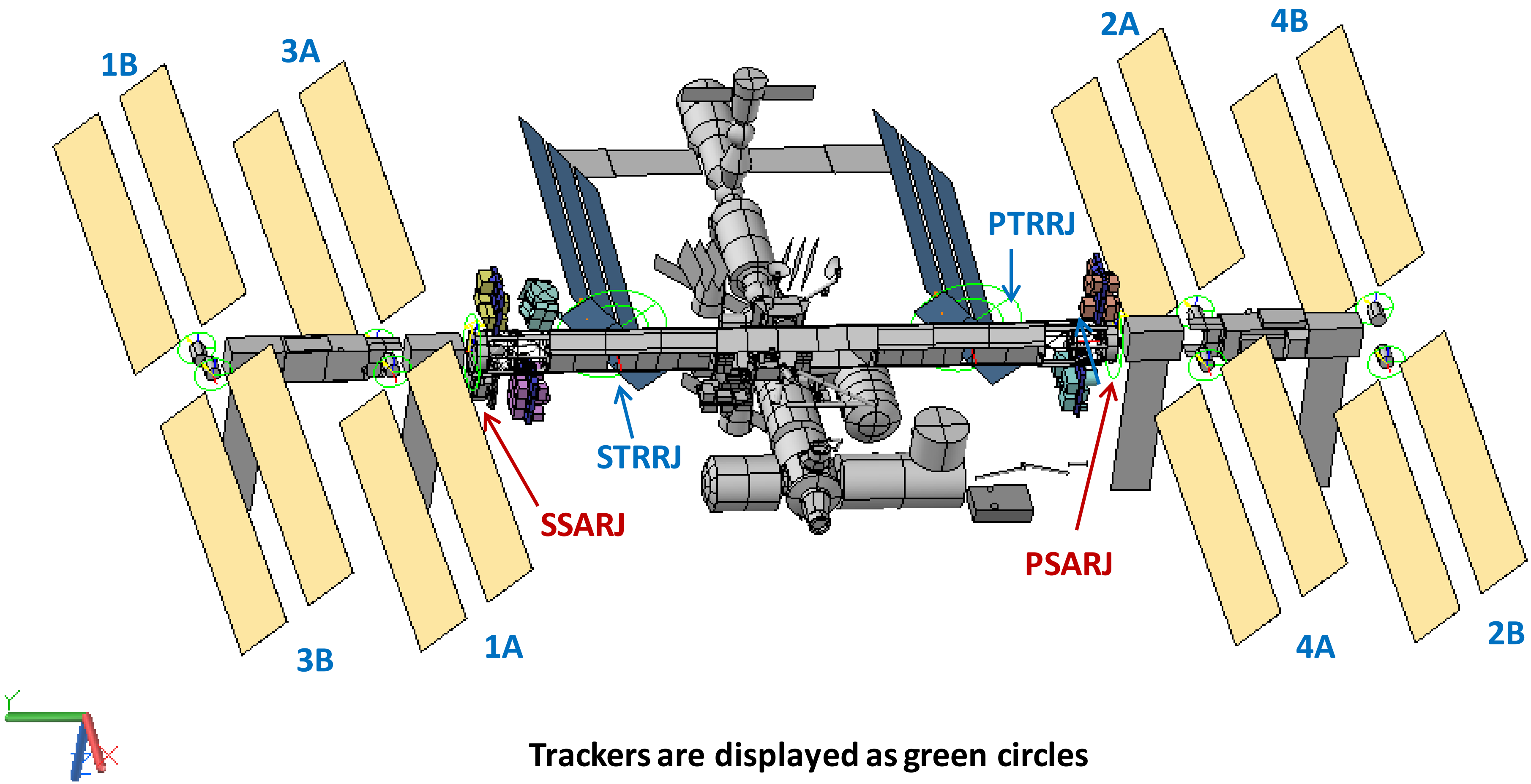
Tracker-Assembly Tree

- Articulator-Detailed Port and Petals::3733
- Articulator-HTV::1E59
- Articulator-Orbital Cygnus::58BF
- Articulator-Orion::57E7
- Articulator-Progress::1E65
- Articulator-SPMA3 and FRGFs::57C5
- Articulator-SPMM::57C1
- Articulator-Soyuz1::1E5A
- Articulator-Soyuz2::1E64
- Articulator-Spacex Dragon ::1E58
- Not in an assembly or tracker
- Tracker-P1 TRRJ::1E1A
- Tracker-P3 SARJ::1DF4
- Tracker-Russian MLM Arrays - SMLMW::1DFA
- Tracker-Russian MLM Radiator - SMLMRD::1E19
- Tracker-Russian SM Arrays - SSMW2::1DF8
- Tracker-Russian SPM PV Arrays::57D9
- Tracker-S1 TRRJ::1E25
- Tracker-S3 SARJ::1DF6

In Model Browser, use "List by Layer" to easily access all Articulators and Trackers.
Use "List by Articulators/ Trackers" to see how Trackers are nested.

All Visiting Vehicle Articulators are pre-set to simulate primary docking/berthing locations. See model documentation for instructions to reposition vehicles to alternate docking/ berthing ports.

ISS Simplified Model – Trackers (US Segment)

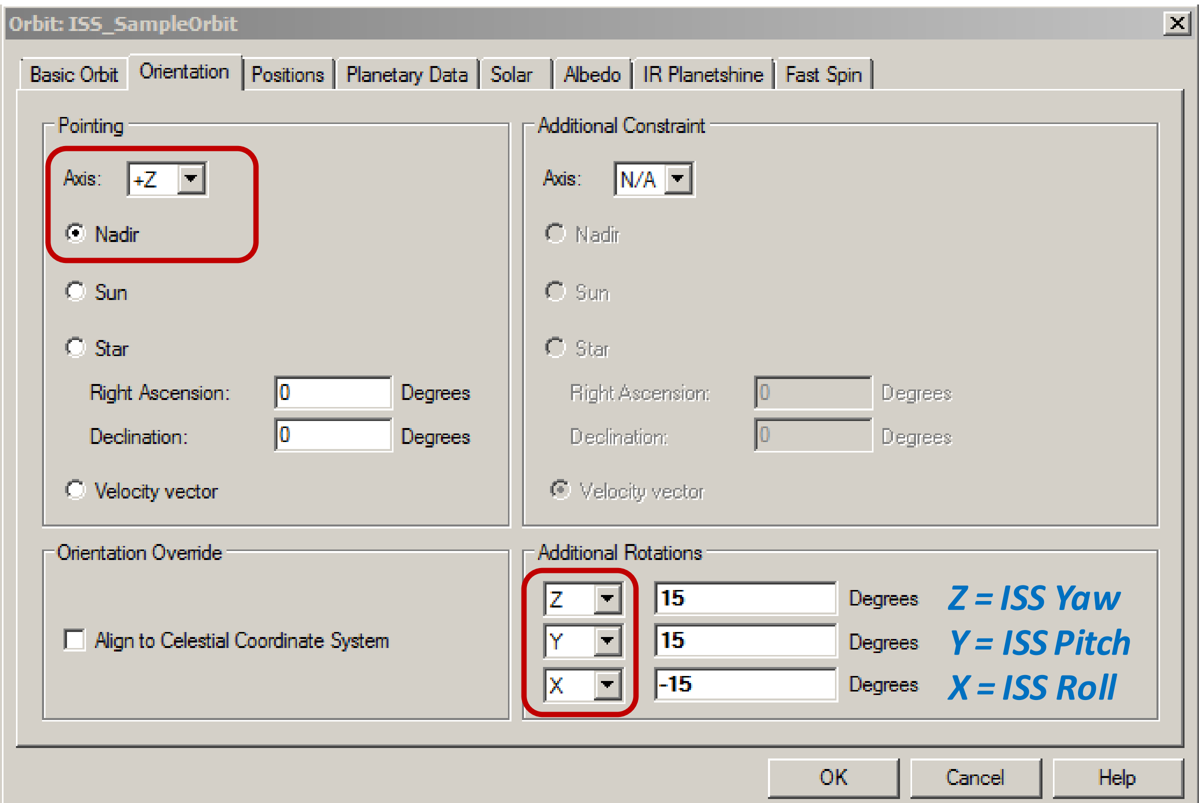


Trackers are displayed as green circles

These "US Segment" trackers are symbol-driven in ISS model-V7R1

ISS Simplified Model – Sample Orbit

- There is one single orbit defined, named ISS_SampleOrbit
  - On the Orbit Orientation tab
    - Pointing is set to +Z Nadir *(do not change this!)*
    - Additional Rotations are set up in the order Z, Y, X (Yaw, Pitch, Roll) *(do not change this!)*
  - All remaining orbital parameters are entered via Symbols

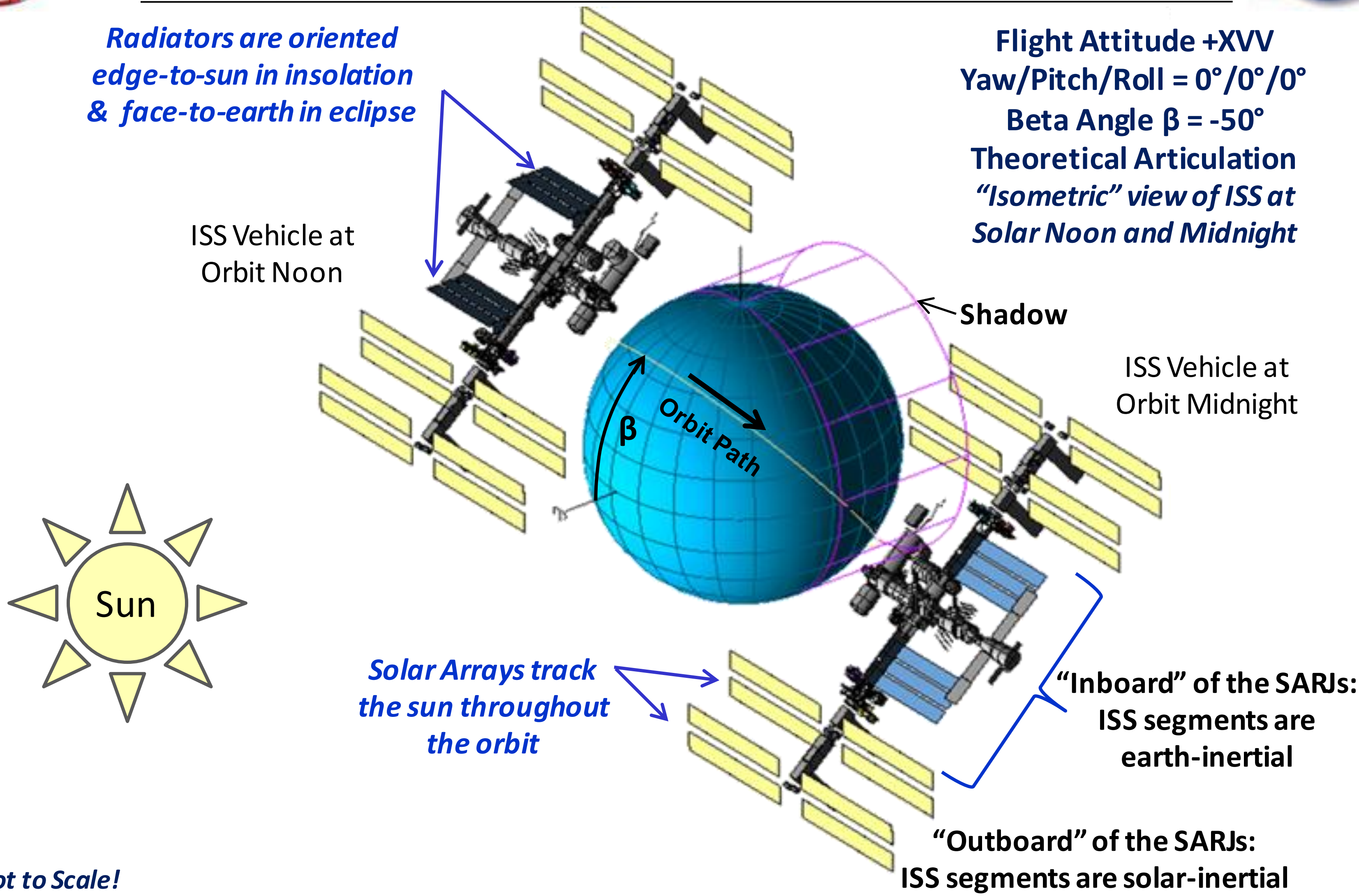


XVV, YVV, and ZVV flight attitudes can be simulated with this single orbit definition

ISS Simplified Model – Orbit Simulation

- Orbit simulations can be useful to gauge relative environments without running a case
- First, Set Global Symbols
  - Symbol Group ISS_Attitude
    - Enter values for Altitude, Yaw, Pitch, Roll, Beta
  - Symbol Group ISS_SARJ-TRRJ_Control
    - Enter control flag for PSARJ, PTRRJ, SSARJ, STRRJ
    - If control flag = 0, also enter the Lock Angle
  - Symbol Group ISS_SolarArray_Control
    - Enter control flag for all 8 Beta Gimbals
    - If control flag = 0, also enter the Lock Angle
- Next, follow instructions in TD Users Manual (Section 6 in TD 5.7 - Displaying Heating Environments)
  - Set Orbit Display Preferences (Section 6.2.1)
    - Set preferences to show planet, shadow grid, orbit path, solar vector, etc.
  - Select pre-set vantage point (Section 6.2.2)
    - The 2 most helpful views are “View from Sun” and “View from Ascending Node”
  - Select vehicle display options (Section 6.2.3)
    - View vehicle at 1 orbit position or multiple positions, animate, etc.
    - For animations, select cycles or start/end time; may also select option to create a movie

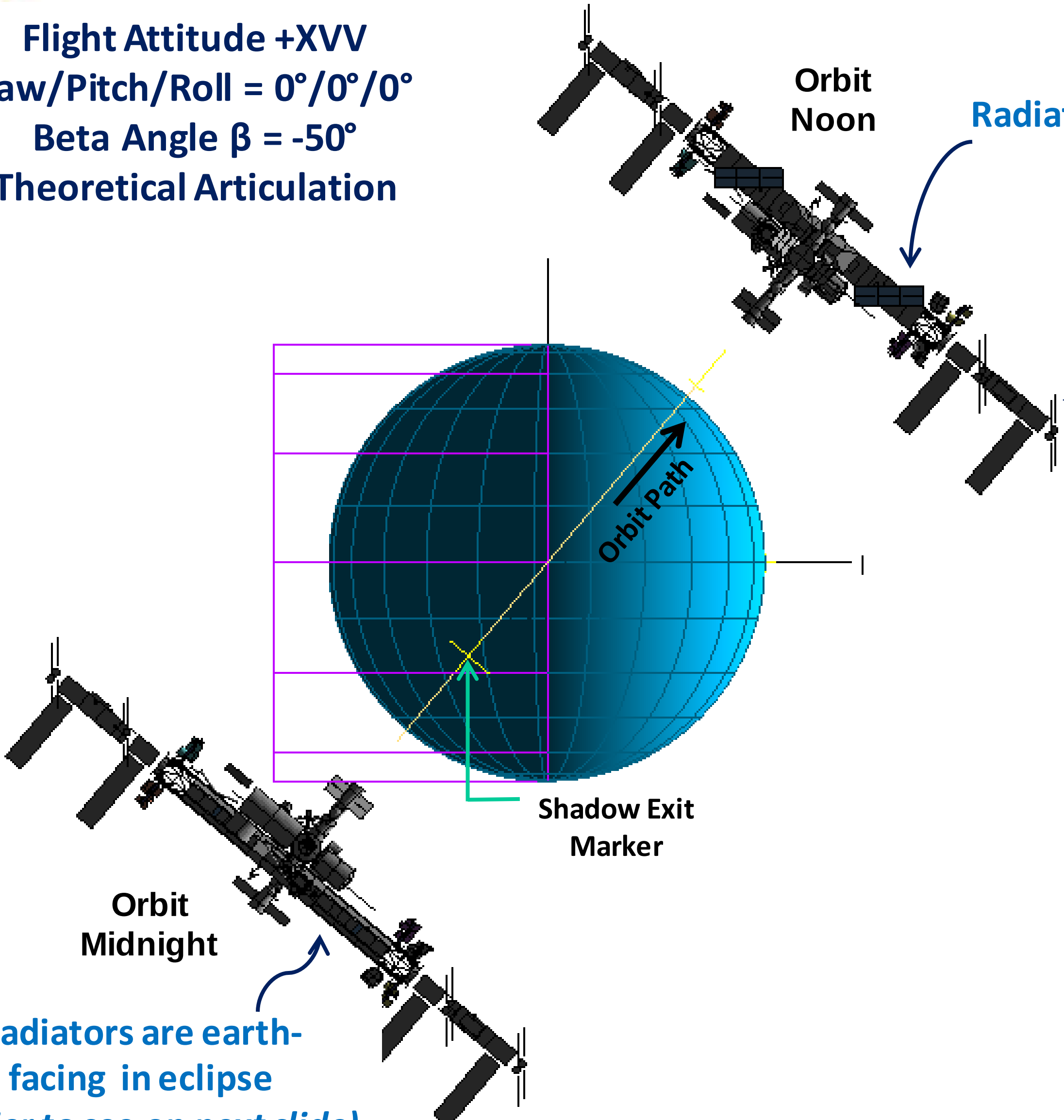
ISS Orbit Illustration



Not to Scale!
The entire ISS Vehicle is either all in sun, or all in eclipse

ISS Example Orbit - Ascending Node View

Flight Attitude +XVV
Yaw/Pitch/Roll = 0°/0°/0°
Beta Angle β = -50°
Theoretical Articulation



Radiators are edge-to-sun in insolation
(easier to see on next slide)

Arrays are perpendicular
to the solar vector
throughout the orbit

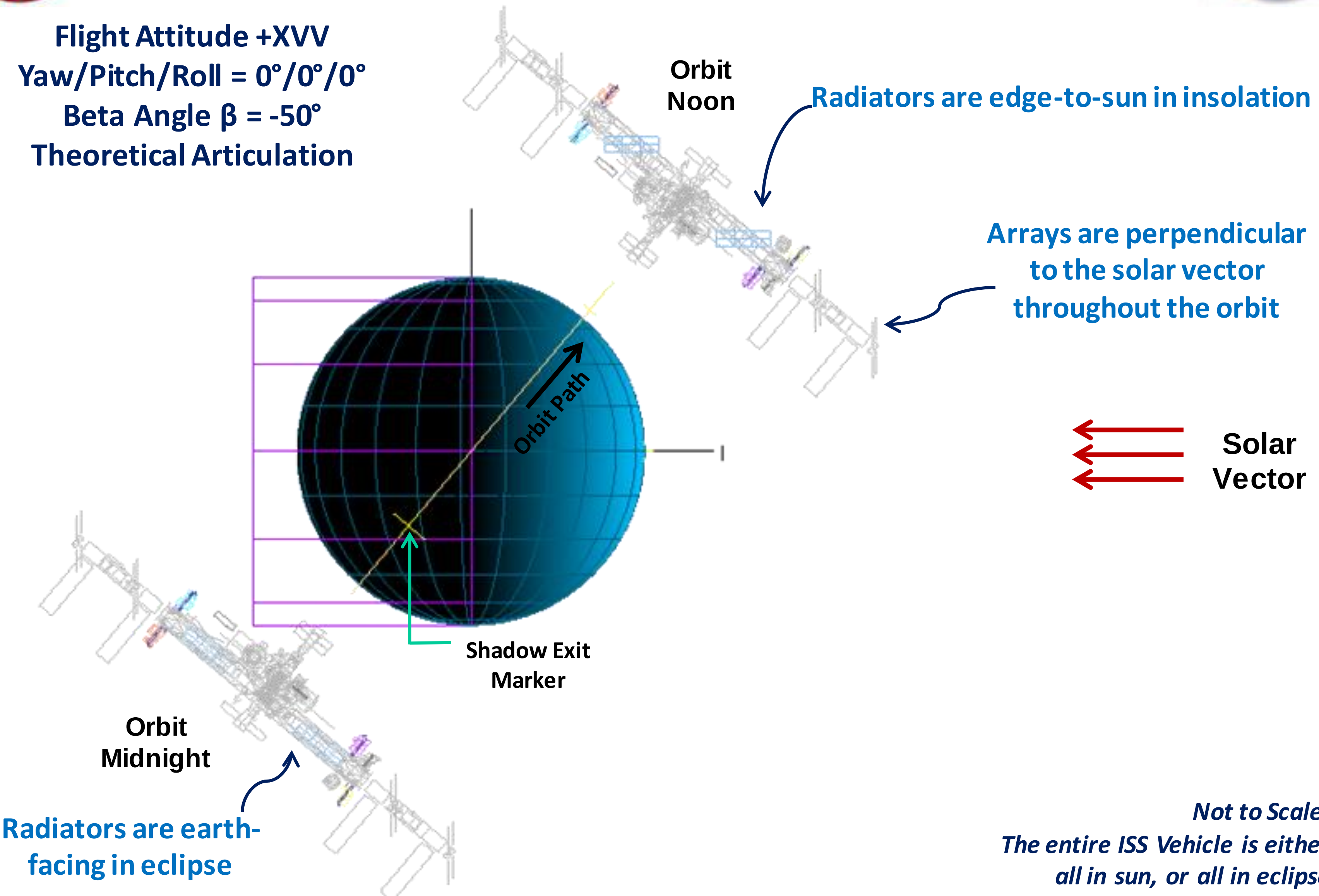
Solar
Vector

Radiators are earth-
facing in eclipse
(easier to see on next slide)

Not to Scale!
The entire ISS Vehicle is either
all in sun, or all in eclipse

ISS Example Orbit - Ascending Node View (wireframe)

Flight Attitude +XVV
Yaw/Pitch/Roll = 0°/0°/0°
Beta Angle β = -50°
Theoretical Articulation



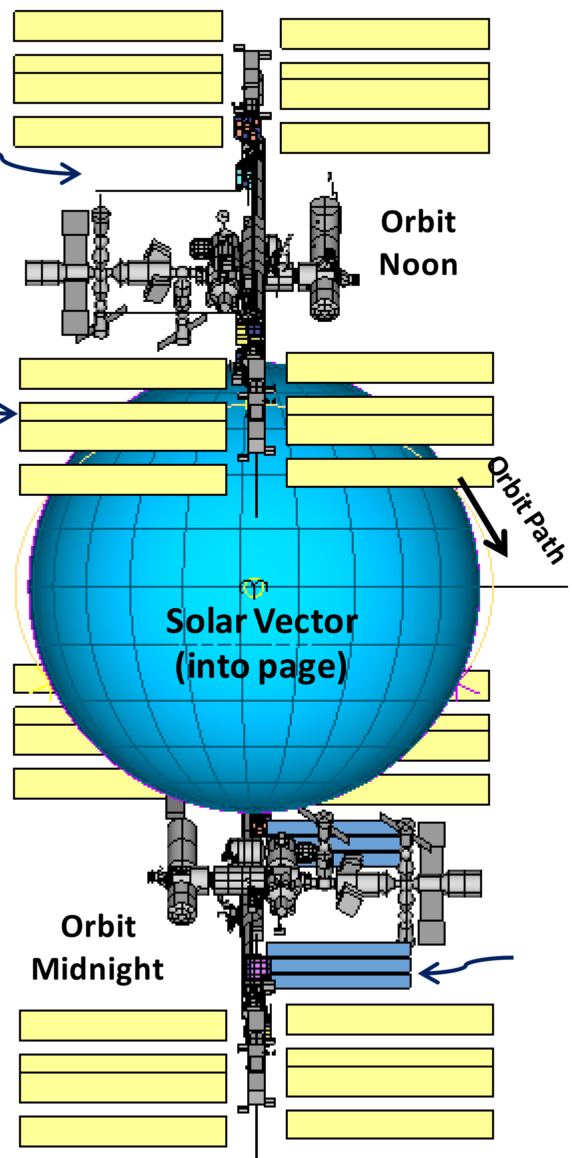
Not to Scale!
The entire ISS Vehicle is either all in sun, or all in eclipse

ISS Example Orbit - Sun View

Flight Attitude +XVV
Yaw/Pitch/Roll = 0°/0°/0°
Beta Angle β = -50°
Theoretical Articulation

Radiators are edge-to-sun during insolation

Arrays are perpendicular to the solar vector throughout the orbit

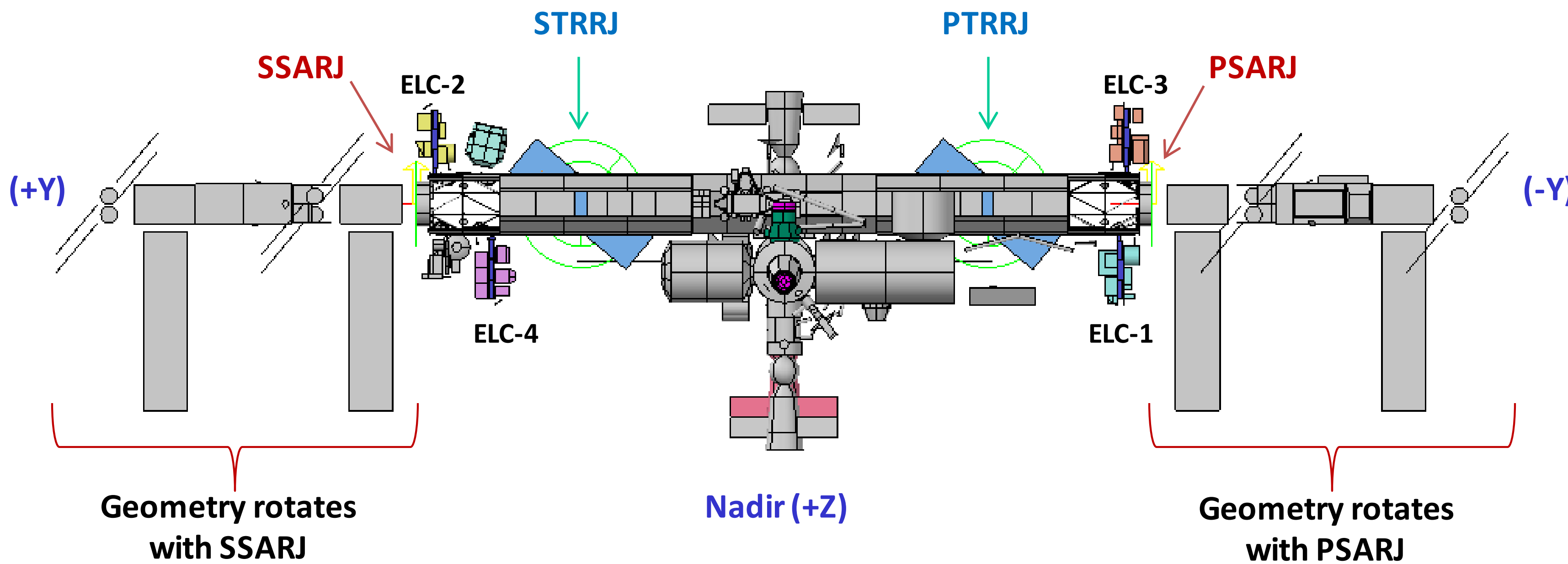


Radiators are earth-facing during eclipse

Not to Scale!
The entire ISS Vehicle is either all in sun, or all in eclipse

ISS Simplified Model – Orbit Simulation

- Simulation of YVV and ZVV attitudes involves parking the Solar Array Rotary Joints (SARJs) and Thermal Radiator Rotary Joints (TRRJs), while allowing the Beta Gimbal Assemblies to sun-track



ISS Simplified Model – Orbit Simulation

- Representative ISS Attitude, YPR, and SARJ/TRRJ Lock Angles in YVV and ZVV:

ISS Attitude				Beta	Park Angles (MOD Convention)			
ISS Attitude	ISS Yaw	ISS Pitch	ISS Roll		Port TRRJ	Stbd TRRJ	Port SARJ	Stbd SARJ
YVV	-90	0	0	0 to -30	0	0	0	0
				-30 to -75	0	0	270	90
ZVV	0	90	0	-75 to +75	90	90	270	90
-ZVV	180	90	0	-75 to +75	90	90	270	90

Note, -YVV is also a valid attitude, flown in the positive Beta range.
It is thermally equivalent to +YVV in the negative beta range.

- An example of symbol settings for YVV, beta -75 is shown in the next slides

ISS Simplified Model – Orbit Simulation

Global Symbol Values for +YVV, Beta -75

Symbol Manager

New Symbol Name:

Group ISS_Attitude

ISS_Attitude | ISS_Configuration | ISS_SARJ-TRRJ_Control | ISS_SolarArray_Control | orbital

Name	Result	Expression	Comment	SINDA	Exp/Val	Type	Unit
ISS_Altitude	215	215	Altitude, nautical miles		Exp		On
ISS_Attitude_01_Yaw	-90	-90	ISS Vehicle Yaw		Exp		On
ISS_Attitude_02_Pitch	0	0	ISS Vehicle Pitch		Exp		On
ISS_Attitude_03_Roll	0	0	ISS Vehicle Roll		Exp		On
ISS_Beta_Angle	-75	-75	Beta Angle		Exp		On
ISS_Env_Albedo	0.2	.2	Solar Albedo		Exp		On
ISS_Env_IR	65	65	IR Constant, Btu/hr-ft^2		Exp		On
ISS_Env_Solar	418.88	418.88	Solar Constant, BTU/hr-ft^2		Exp		On

Symbol Manager

New Symbol Name: Add

Group ISS_SARJ-TRRJ_Control

ISS_Attitude | ISS_Configuration | ISS_SARJ-TRRJ_Control | ISS_SolarArray_Control | orbital

Name	Result	Expression	Comment	SINDA	Exp/Val	Type	Units
ISS_Control_PSARJ	0	0	Set to 0 if Port SARJ is locked, or 1 if rotating		Exp		On
ISS_Control_PTRRJ	0	0	Set to 0 if Port TRRJ is locked, or 1 if rotating		Exp		On
ISS_Control_SSARJ	0	0	Set to 0 if Starboard SARJ is locked, or 1 if rotating		Exp		On
ISS_Control_STRRJ	0	0	Set to 0 if Starboard TRRJ is locked, or 1 if rotating		Exp		On
ISS_PSARJ	270	270	PSARJ Lock Angle, MOD convention (degrees), applica...		Exp		On
ISS_PTRRJ	0	0	PTRRJ Lock Angle, MOD convention (degrees), applica...		Exp		On
ISS_SSARJ	90	90	SSARJ Lock Angle, MOD convention (degrees), applica...		Exp		On
ISS_STRRJ	0	0	STRRJ Lock Angle, MOD convention (degrees), applica...		Exp		On

ISS Simplified Model – Orbit Simulation

Global Symbol Values for +YVV, Beta -75 (continued)

Group ISS_Solar Array_Control

Symbol Manager

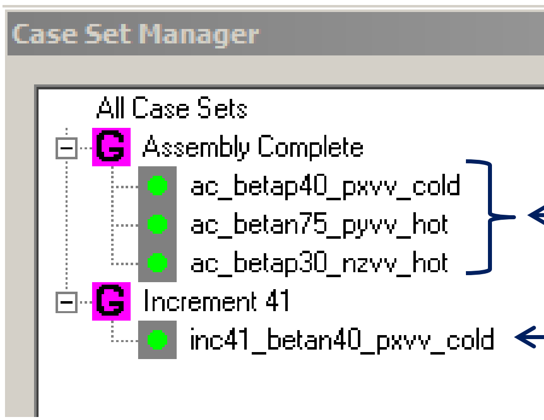
New Symbol Name: [ ] Add

ISS_Attitude | ISS_Configuration | ISS_SARJ-TRRJ_Control | ISS_SolarArray_Control | orbital

Name	Result	Expression	Comment	SINDA	Exp/Val	Type	Units
ISS_Control_P4_BETA2A	1	1	Set to 0 if Array P4_2A is locked, or 1 if sun-tracking		Exp		On
ISS_Control_P4_BETA4A	1	1	Set to 0 if Array P4_4A is locked, or 1 if sun-tracking		Exp		On
ISS_Control_P6_BETA2B	1	1	Set to 0 if Array P6_2B is locked, or 1 if sun-tracking		Exp		On
ISS_Control_P6_BETA4B	1	1	Set to 0 if Array P6_4B is locked, or 1 if sun-tracking		Exp		On
ISS_Control_S4_BETA1A	1	1	Set to 0 if Array S4_1A is locked, or 1 if sun-tracking		Exp		On
ISS_Control_S4_BETA3A	1	1	Set to 0 if Array S4_3A is locked, or 1 if sun-tracking		Exp		On
ISS_Control_S6_BETA1B	1	1	Set to 0 if Array S6_1B is locked, or 1 if sun-tracking		Exp		On
ISS_Control_S6_BETA3B	1	1	Set to 0 if Array S6_3B is locked, or 1 if sun-tracking		Exp		On
ISS_P4_BETA2A	0	0	Solar Array P4_2A Lock Angle, MOD convention, applicabl...		Exp		On
ISS_P4_BETA4A	0	0	Solar Array P4_4A Lock Angle, MOD convention, applicabl...		Exp		On
ISS_P6_BETA2B	0	0	Solar Array P6_2B Lock Angle, MOD convention, applicabl...		Exp		On
ISS_P6_BETA4B	0	0	Solar Array P6_4B Lock Angle, MOD convention, applicabl...		Exp		On
ISS_S4_BETA1A	0	0	Solar Array S4_1A Lock Angle, MOD convention, applicabl...		Exp		On
ISS_S4_BETA3A	0	0	Solar Array S4_3A Lock Angle, MOD convention, applicabl...		Exp		On
ISS_S6_BETA1B	0	0	Solar Array S6_1B Lock Angle, MOD convention, applicabl...		Exp		On
ISS_S6_BETA3B	0	0	Solar Array S6_3B Lock Angle, MOD convention, applicabl...		Exp		On

ISS Simplified Model – Case Set

- Sample cases are provided with the model, and set-up instructions are provided in the model documentation



<u>Assembly Complete</u>
Beta +40, +XVV, cold case
Beta -75, +YVV, hot case
Beta +30, -ZVV, hot case
<u>Increment 41</u>
Beta -40, +XVV, cold case

- The differences between these sample cases are:
  - Radiation Tab – Radiation and heating rate tasks are defined with appropriate Radiation Analysis Group for the specific ISS Stage
  - SINDA Tab – User-defined SINDA build is set for appropriate ISS Stage
  - Props Tab – Optical Property Database override is checked and appropriate database file is selected, either BOL or EOL
  - Symbols Tab – Symbol overrides are selected for all ISS-model symbols, and each sample case has a unique set of symbol overrides, see next slides

ISS Simplified Model – Case Set

Sample Case Symbol Overrides

Case Description	Assembly Complete			Incr 41
	XVV, beta +40, Cold Case, Theoretical Articulation	YVV, beta -75, Hot Case, Locked Port/Stbd TRRJ and SARJ	-ZVV, beta +30, Hot Case, Locked Port/Stbd TRRJ and SARJ	XVV, beta -40, Cold Case, Theoretical Articulation
Case Set Name	ac_betap40_ pxvv_cold	ac_betan75_ pyvv_hot	ac_betap30_ nzvv_hot	inc41_betan40_ pxvv_cold
Optical Property Override	issac_v7r1_v0_ bol.rco	issac_v7r1_v0_ eol.rco	issac_v7r1_v0_ eol.rco	issac_v7r1_v0_ bol.rco
Radiation Analysis Group	AC Stage - Baseline v7r1	AC Stage - Baseline v7r1	AC Stage - Baseline v7r1	Increment 41 Stage - v7r1
Orbit	ISS_SampleOrbit	ISS_SampleOrbit	ISS_SampleOrbit	ISS_SampleOrbit
Symbol Overrides				
IHEATS	0	2	2	0
ISS_AC_Flag	1	1	1	0
ISS_Altitude	215	215	215	215
ISS_Attitude_01_Yaw	0	-90	180	0
ISS_Attitude_02_Pitch	-2.5	0	90	-2.5
ISS_Attitude_03_Roll	0	0	0	0
ISS_Beta_Angle	40	-75	30	-40
ISS_Control_P4_BETA2A	1	1	1	1
ISS_Control_P4_BETA4A	1	1	1	1
ISS_Control_P6_BETA2B	1	1	1	1
ISS_Control_P6_BETA4B	1	1	1	1
ISS_Control_PSARJ	1	0	0	1
ISS_Control_PTRRJ	1	0	0	1
ISS_Control_S4_BETA1A	1	1	1	1
ISS_Control_S4_BETA3A	1	1	1	1
ISS_Control_S6_BETA1B	1	1	1	1
ISS_Control_S6_BETA3B	1	1	1	1
ISS_Control_SSARJ	1	0	0	1
ISS_Control_STRRJ	1	0	0	1

list continued on next slide

ISS Simplified Model – Case Set

Sample Case Symbol Overrides

	Assembly Complete			Incr 41
Case Description	XVV, beta +40, Cold Case, Theoretical Articulation	YVV, beta -75, Hot Case, Locked Port/Stbd TRRJ and SARJ	-ZVV, beta +30, Hot Case, Locked Port/Stbd TRRJ and SARJ	XVV, beta -40, Cold Case, Theoretical Articulation
Case Set Name	ac_betap40_ pxvv_cold	ac_betan75_ pyvv_hot	ac_betap30_ nzvv_hot	inc41_betan40_ pxvv_cold
Optical Property Override	issac_v7r1_v0_ bol.rco	issac_v7r1_v0_ eol.rco	issac_v7r1_v0_ eol.rco	issac_v7r1_v0_ bol.rco
Radiation Analysis Group	AC Stage - Baseline v7r1	AC Stage - Baseline v7r1	AC Stage - Baseline v7r1	Increment 41 Stage - v7r1
Orbit	ISS_SampleOrbit	ISS_SampleOrbit	ISS_SampleOrbit	ISS_SampleOrbit
Symbol Overrides				
ISS_Env_Albedo	0.2	0.4	0.4	0.2
ISS_Env_IR	65	90.7	90.7	65
ISS_Env_Solar	418.88	451	451	418.88
ISS_P4_BETA2A	0	0	0	0
ISS_P4_BETA4A	0	0	0	0
ISS_P6_BETA2B	0	0	0	0
ISS_P6_BETA4B	0	0	0	0
ISS_PSARJ	0	270	270	0
ISS_PTRRJ	0	0	90	0
ISS_S4_BETA1A	0	0	0	0
ISS_S4_BETA3A	0	0	0	0
ISS_S6_BETA1B	0	0	0	0
ISS_S6_BETA3B	0	0	0	0
ISS_SSARJ	0	90	90	0
ISS_STRRJ	0	0	90	0

ISS Simplified Model – Model Setup for Payload Analysis

- Any ISS Stage + Payload (+ Visiting Vehicle) may be simulated following these general steps:
  - Integrate payload model into the ISS model
    - Recommend that an analysis group be set up with just the payload geometry
  - Define an Analysis Group containing all relevant geometry
    - Recommend using the "Merge" feature in Radiation Analysis Group Manager to combine pre-defined groups, i.e., ISS Stage + Payload (+Visiting Vehicle)
  - Set symbol ISS_AC_FLAG, controls the position of some ISS modules
  - Within a Case Set
    - Define radiation and heating rate tasks for the specific Analysis Group on the Radiation Tab
    - Select Submodels to build via a User-Defined SINDA Build on the SINDA Tab *(Do not use "Build All")*
    - Use the Property Override Tab to select either BOL or EOL optical properties
    - Use the Symbol Override Tab to set case-specific symbols

7. Integration Lessons Learned

Caryn Preston

Integration Steps/Lessons

- Before you begin,
  - In case you need to start over, set aside a copy of the ISS and payload models!
  - Ensure that there is no conflict in names for optical properties, symbols, submodels, layers, Analysis Groups between the two models
- Follow instructions in the TD Users Manual, Section 18.2.1 in TD 5.7, for importing a TD model. Some tips:
  - Integrate the payload model into the ISS model, not the other way around
  - Ensure that both models are in the same units
  - Ensure the World Coordinate System (WCS) is oriented in the same way in both models, if importing the payload model into the same location/orientation in the ISS model
  - Remember to toggle off Articulators (Thermal -> Articulators/Trackers -> Toggle Global Activation) in the ISS model (and the payload model, if applicable) just before & just after importing

Integration Steps/Lessons

- After the payload model is integrated into the ISS model and positioned in the model in the appropriate location,
  - Create a Radiation Analysis Group containing just the Payload
  - Create Radiation Analysis Group(s) of ISS Stage + Payload (+ Visiting Vehicle) using the “Merge” feature in Radiation Analysis Group Manager
  - Set up Case Sets(s) for integrated payload analysis
    - Tip: Start with a copy of one of the ISS model sample cases
    - Radiation Tab: set up radiation and heating rate calculations
    - SINDA Tab: edit the User-Defined SINDA Build statement, include appropriate submodels
    - Props Tab: set optical property database overrides
    - Symbols Tab: set symbol overrides

Integration Steps/Lessons

For models delivered to ISS-PTCS for Flight Product Support

- Payload model delivery milestones for integrated thermal analyses by the Launch Provider and ISS integrator is defined in Section 5.3 of JSC-66617

L-16 months:
PD submits CDR-quality Thermal Model

→

ISS-PTCS performs model checkout; focus is on model applicability for launch, transfer to ISS, and on-orbit ISS sustaining analysis

→

L-13 months:
ISS-PTCS submits checked-out model to end-users (Launch Provider, ISS Sustainer)

L-9 months:
PD submits final Thermal Model & Update Summary including evaluation of critical node impacts

→

NASA and end-users evaluate model changes and PD-provided recommendations to determine if rework is warranted by Launch Provider, ISS Sustainer

→

L-6 months :
For ELC-based payloads, ISS-PTCS converts the L-9 model to TRASYS/SINDA and performs ELC-re-verification analysis

Milestone dates are stated in months before launch

PD = Payload Developer

Integration Steps/Lessons

- For models delivered to ISS-PTCS
  - Please follow model guidelines in JSC-66617, Section 5
    - Document defines model formats, delivery schedules, etc.
    - Pay attention to submodel naming conventions
  - Ensure model has at least one sample case set that runs
  - For TD models, create separate “internal” radiation analysis group(s) if possible
  - Ensure model documentation includes the following
    - Clear instructions on how to set up the model for the relevant mission phases, for Launch Provider and ISS Sustaining analyses (typically launch, transfer, and on-orbit survival)
    - A critical nodes list and limits
  - After model delivery, keep a change log in case a revised model needs to be delivered to PTCS, please include a description of changes and impacts to critical nodes

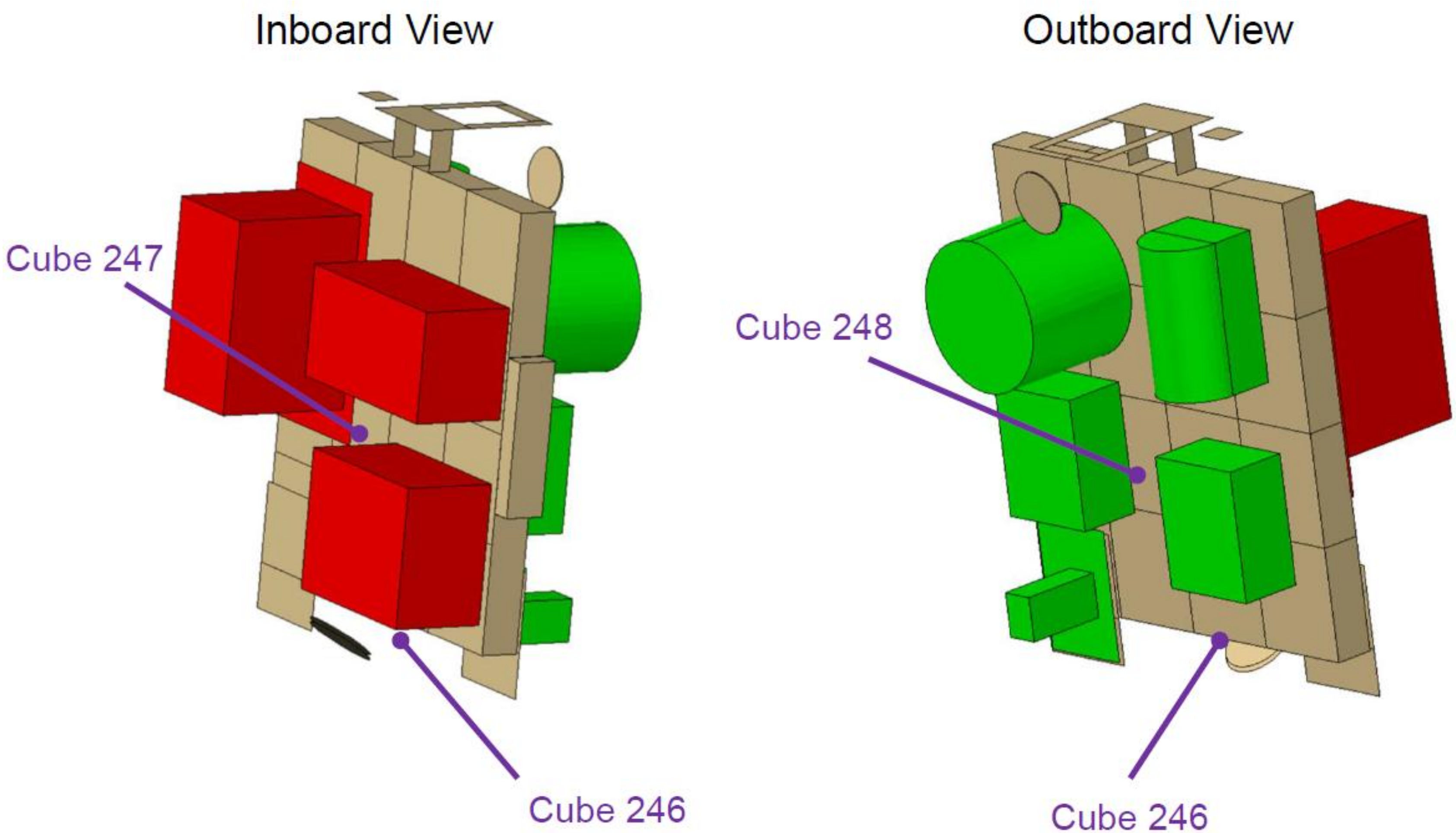
8. Conclusions

Conclusions

- There are numerous ISS resources available to a payload developer
  - The ISS Program provides support for ISS operations and payload interfaces
  - ISS-PTCS Team provides reduced-fidelity launch vehicle and ISS models that are maintained under configuration control
    - User-friendly features have been added to the ISS Reduced Fidelity Model, simulating key operational aspects of the ISS
  - ISS-PTCS Team provides payload model checkout services prior to model delivery to launch provider and ISS-sustainer; checkout ensures credible constraints for launch vehicle and transfer to ISS external site, but does not address payload on-orbit mission success
- Integrated thermal analysis with PTCS-provided models is recommended to understand how planned missions phases and ISS operations can impact a payload's thermal environment
  - To reduce risk to mission success, a payload developer should consider the induced thermal environments throughout all planned mission phases early on in the design process
  - Key parameters impacting on-orbit environments – such as variations in solar flux, optical properties, solar beta angle, ISS flight orientation, attitude and altitude, ISS rotating geometry, and plume heating -- can be addressed in an integrated analysis
  - An example of integrated thermal analysis has been provided – representative ISS environments (flux cubes) at the ELC and JEM Airlock worksites – that are useful as a general guide
    - Considers the solar beta trend for a nominal ISS attitude; based on a 6-sided average, applicability for specific payload components must be determined on a case-by-case basis

8. Q&A

ELC-1 Geometry



Section 5 Appendix

Cube 246 (Nadir) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-17	N/A	N/A	11	N/A	N/A	83
+60	-47 (U)	-16	-24	-47 (U)	19	4	-47 (U)	101	74
+45	-49	-11	-21	-49	28	10	-49	117	85
+30	-50	-6 (U)	-20	-50	39 (U)	16	-50	137 (U)	97
0	-51 (L)	-20 (L)	-31 (L)	-51 (L)	14 (L)	-6 (L)	-51 (L)	96 (L)	59 (L)
-30	-50	-16	-27	-50	26	4	-50	117	80
-45	-50	-9	-20	-50	37	17 (U)	-50	136	103 (U)
-60	-49	-12	-21	-49	30	14	-49	122	95
-75	N/A	N/A	-17 (U)	N/A	N/A	14	N/A	N/A	91

- Minimum orbit average occurs at beta 0°.
- Night pass range is -47° C to -50° C and independent of optical property ratio.
  - Little or no solar flux during night pass
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Section 5 Appendix

Cube 247 (Inboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-20	N/A	N/A	-8	N/A	N/A	31
+60	-39 (U)	-23 (L)	-27 (L)	-39 (U)	-11 (L)	-18 (L)	-39 (U)	27 (L)	13 (L)
+45	-40	-20	-26	-40	-6	-16	-40	38	19
+30	-42	-18	-26	-42	3	-11	-42	60	34
0	-46 (L)	-8	-21	-46 (L)	30	8	-46 (L)	118	79
-30	-44	3	-12 (U)	-44	43 (U)	19 (U)	-44	135 (U)	96 (U)
-45	-44	-4	-14	-44	32	14	-44	116	87
-60	-44	-3 (U)	-13	-44	32	16	-44	116	89
-75	N/A	N/A	-16	N/A	N/A	7	N/A	N/A	69

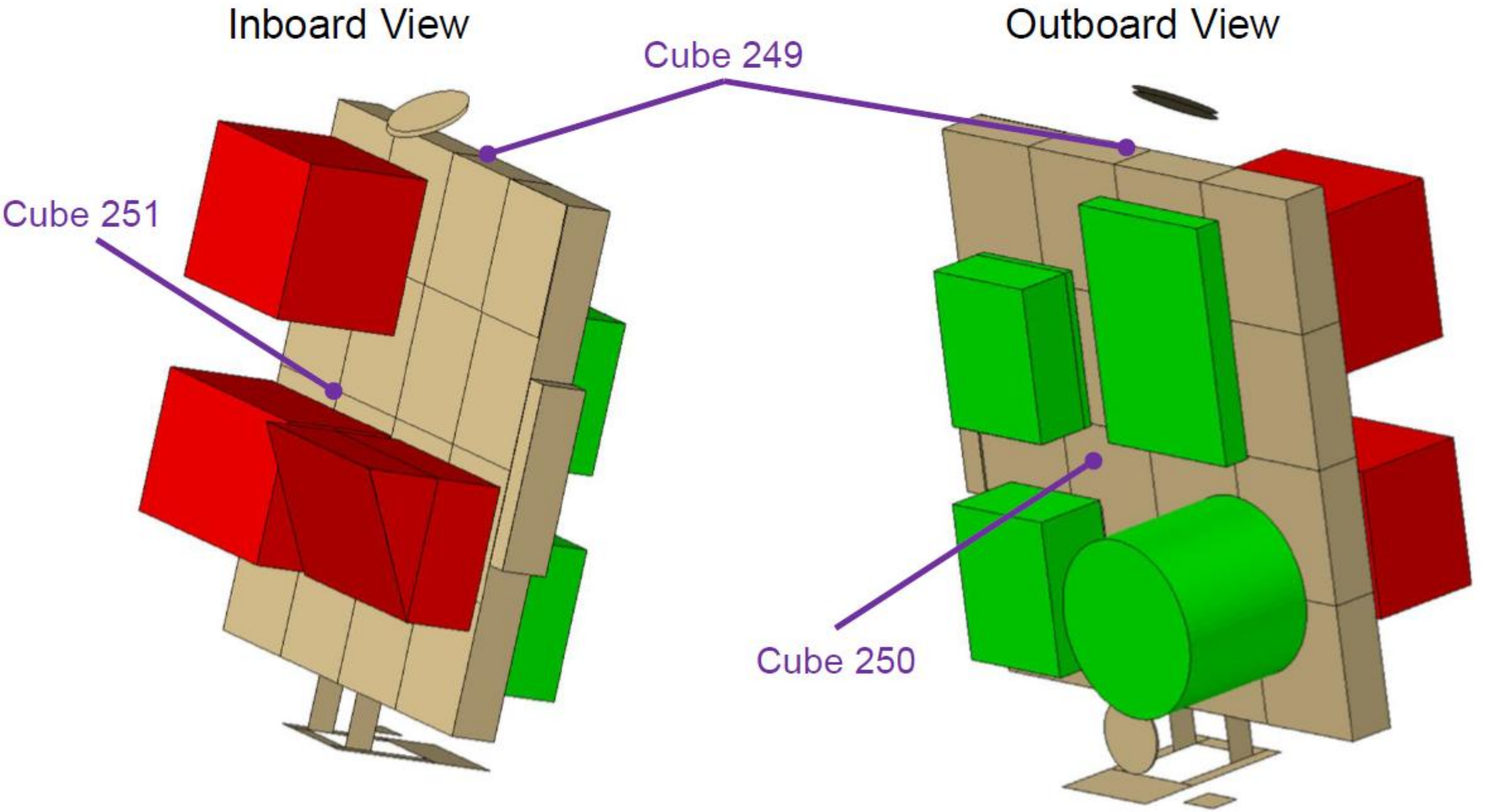
- Minimum orbit average temperatures occurs at +60°.
- Night pass range is from -46 C to -39 C.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Cube 248 (Outboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	7 (U)	N/A	N/A	39 (U)	N/A	N/A	119 (U)
+60	-41 (U)	4	-7	-42 (U)	42	24	-42 (U)	130	101
+45	-44	12 (U)	-3	-44	56 (U)	33	-44	155 (U)	118
+30	-47	9	-8	-47	54	28	-47	154	112
0	-50 (L)	-11	-24	-50 (L)	31	7	-50 (L)	122	81
-30	-46	-23	-31 (L)	-46	-1	-14	-46	61	34
-45	-47	-24	-31 (L)	-47	-9	-19	-47	36	16
-60	-46	-25 (L)	-30	-46	-13 (L)	-21 (L)	-46	23 (L)	9 (L)
-75	N/A	N/A	-23	N/A	N/A	-12	N/A	N/A	26

- Beta angle at which orbit average minimum temperature occurs depends on optical property ratio.
- The night pass range is -50° C to -41° C.
  - Provides opportunity to thermal condition payload before installing.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

ELC-2 Geometry



Cube 249 (Zenith) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-32 (U)	N/A	N/A	11	N/A	N/A	102
+60	-83 (U)	-19	-32 (U)	-83 (U)	33	13 (U)	-83 (U)	137	107 (U)
+45	-84	-18	-34	-84	32	8	-84	135	98
+30	-85	-16 (U)	-34	-85	39 (U)	11	-85	147	103
0	-89 (L)	-22	-41 (L)	-89 (L)	31	2	-89 (L)	136	91
-30	-85	-19	-37	-85	38	10	-85	148 (U)	105
-45	-84	-21	-37	-84	32	7	-84	137	99
-60	-84	-30 (L)	-41 (L)	-84	16 (L)	-2	-84	110 (U)	83
-75	N/A	N/A	-40	N/A	N/A	-3 (L)	N/A	N/A	79 (U)

- The orbit average minimum occurs at solar beta angles of -60° or -75° for optical property ratios listed.
  - Optical Ratio 1 also has orbit average minimum at solar beta 0°.
- The night pass temperature range is -89° C to -83° C.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Section 5 Appendix

Cube 251 (Inboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-31	N/A	N/A	-22	N/A	N/A	8
+60	-60	-17	-26	-60	-3	-14	-60	40	23
+45	-58	-7	-21	-58	14	-4	-58	73	46
+30	-58	6	-13	-58	47 (U)	21	-58	142 (U)	101 (U)
0	-63 (L)	-3	-22	-63 (L)	41	13	-63 (L)	138	95
-30	-60	8 (U)	-11 (U)	-60	47	21 (U)	-60	137	97
-45	-59	-10	-23	-59	8	-8	-59	62	36
-60	-57 (U)	-28 (L)	-35	-57 (U)	-17 (L)	-26	-57 (U)	18 (L)	3
-75	N/A	N/A	-39 (L)	N/A	N/A	-33 (L)	N/A	N/A	-9 (L)

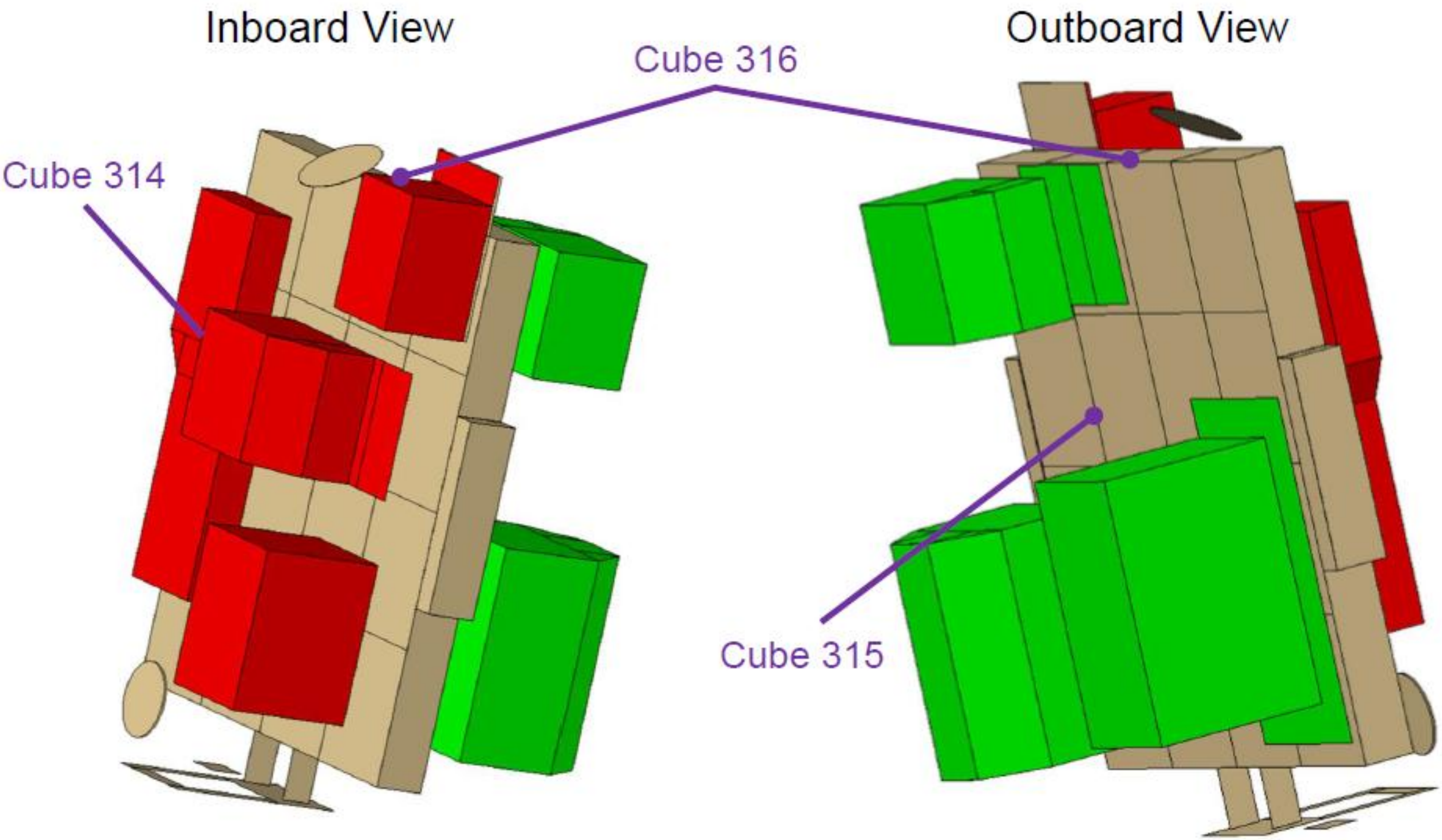
- The orbit minimum temperature occurred at solar beta -75° for all optical property ratios listed.
- The night pass temperature range is -63° C to -57° C with minimum value occurring at solar beta 0°.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Cube 250 (Outboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-32	N/A	N/A	-22	N/A	N/A	12 (L)
+60	-64	-28 (L)	-37 (L)	-64	-19 (L)	-24 (L)	-64	31 (L)	14
+45	-66	-23	-35	-66	-3	-19	-66	52	27
+30	-68	-12	-28	-68	27	3	-68	116	77
0	-73 (L)	-12	-31	-73 (L)	36	8	-73 (L)	137	93
-30	-66	1	-17	-66	51	23	-66	156 (U)	112
-45	-64	7 (U)	-10	-64	53 (U)	29	-64	154	118
-60	-62 (U)	6	-8	-62 (U)	51	31	-62 (U)	149	119
-75	N/A	N/A	4 (U)	N/A	N/A	44 (U)	N/A	N/A	138 (U)

- The orbit average minimum temperature occurs at either solar beta angles of +60° or +75° for the optical property ratios listed.
- The night pass temperature range is -73° C to -62° C with minimum value occurring at solar beta 0°.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

ELC-3 Geometry



Section 5 Appendix

Cube 316 (Zenith) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-41	N/A	N/A	-7 (L)	N/A	N/A	71 (L)
+60	-82	-32 (L)	-42	-82	11 (U)	-6	-82	102 (L)	76
+45	-81 (U)	-21	-36	-81 (U)	32	8	-81 (U)	137	99
+30	-81 (U)	-20	-37	-81 (U)	38	11	-81 (U)	149 (U)	106
0	-88 (L)	-24	-43 (L)	-88 (L)	30	1	-88 (L)	135	91
-30	-83	-16 (U)	-34	-83	38 (L)	11	-83	146	103
-45	-82	-19	-34	-82	33	9	-82	137	101
-60	-81 (U)	-21	-33	-81 (U)	29	11	-81 (U)	130	102
-75	N/A	N/A	-27 (U)	N/A	N/A	19 (U)	N/A	N/A	113 (U)

- For ratio 1, all environment temperatures are below slide table critical node limit with a 30 C environment change between solar beta +30° and 0°.
- The night pass temperature range is -88° C to -81° C with minimum value occurring at solar beta 0°.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Cube 314 (Inboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-42	N/A	N/A	-29	N/A	N/A	8
+60	-59	-40 (L)	-44 (L)	-59	-26 (L)	-33 (L)	-59	18 (L)	3 (L)
+45	-61	-36	-43	-61	-17	-28	-61	38	16
+30	-63	-30	-41	-63	2	-17	-63	77	44
0	-66 (L)	-17	-32	-66 (L)	34	8	-66 (L)	138	94
-30	-61	1 (U)	-17	-61	54 (U)	26	-61	162 (U)	118
-45	-59	1 (U)	-15	-59	51	26	-59	155	116
-60	-58 (U)	1 (U)	-11	-58 (U)	47	29	-58 (U)	147	119 (U)
-75	N/A	N/A	-8 (U)	N/A	N/A	31 (U)	N/A	N/A	119

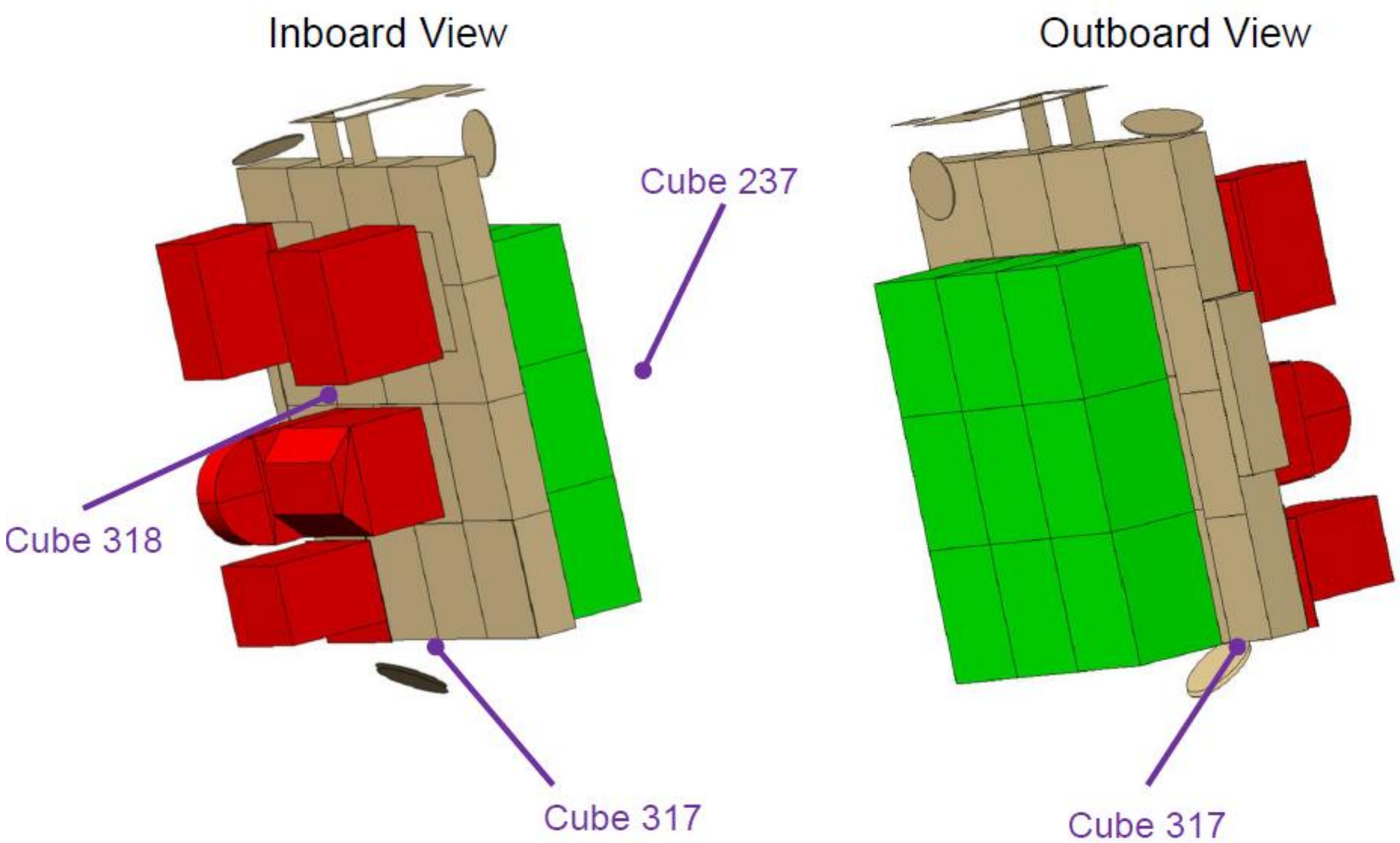
- For ratio 1, all environment temperatures are below slide table critical node limit with a 30 C environment change between solar beta +30° and 0°.
- The night pass temperature range is -66° C to -58° C with minimum value occurring at solar beta 0°.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Cube 315 (Outboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-3 (U)	N/A	N/A	36 (U)	N/A	N/A	126 (U)
+60	-56 (U)	1	-11	-56 (U)	45	26	-56 (U)	141	112
+45	-57	3 (U)	-12	-57	49	26	-57	150	113
+30	-60	-1	-18	-60	50 (U)	23	-60	155 (U)	112
0	-69 (L)	-13	-30	-69 (L)	36	8	-69 (L)	137	93
-30	-63	-13	-28	-63	27	3	-63	116	78
-45	-61	-22	-33	-61	2	-14	-61	66	39
-60	-58	-27 (L)	-34 (L)	-58	-11 (L)	-21 (L)	-58	39 (L)	22
-75	N/A	N/A	-30	N/A	N/A	-20	N/A	N/A	12 (L)

- For ratio 1, all environment temperatures are below slide table critical node limit with a 30 C environment change between solar beta +30° and 0°.
- The night pass temperature range is -69° C to -56° C with minimum value occurring at solar beta 0°
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

ELC-4 Geometry



Section 5 Appendix

Cube 317 (Nadir) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-39 (L)	N/A	N/A	11	N/A	N/A	108 (U)
+60	-36	-11	-17	-36	24	11	-36	106	80
+45	-35 (U)	-2 (U)	-12 (U)	-35 (U)	40 (U)	22 (U)	-35 (U)	134 (U)	101
+30	-37 (L)	-9	-18	-37 (L)	29	10	-37 (L)	116	81
0	-36	-12	-20	-36	22	3	-36	102	66
-30	-35 (U)	-13	-20	-35 (U)	16 (L)	1 (L)	-35 (U)	87 (L)	57 (L)
-45	-36	-12	-19	-36	17	3	-36	91	65
-60	-36	-15 (L)	-21	-36	18	5	-36	97	71
-75	N/A	N/A	-14	N/A	N/A	14	N/A	N/A	86

- For ratio 1, all environment temperatures are below slide table critical node limit with a 30 C environment change between solar beta +30° and 0°.
- The night pass temperature range is -37° C to -35° C with minimum value occurring at solar beta +30°
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Cube 318 (Inboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-8 (U)	N/A	N/A	27 (U)	N/A	N/A	111 (U)
+60	-45	-3	-13	-45	36	19	-45	126	98
+45	-44 (U)	-6	-16	-44 (U)	28	11	-44 (U)	109	81
+30	-46	-2 (U)	-16	-46	38 (U)	16	-46	130 (U)	93
0	-47 (L)	-12	-23	-47 (L)	23	3	-47 (L)	106	69
-30	-45	-17	-26	-45	11	-6	-45	82	51
-45	-44 (U)	-23	-29	-44 (U)	-4	-15	-44 (U)	52	29
-60	-45	-31 (L)	-34 (L)	-45	-20 (L)	-26	-45	15 (L)	2
-75	N/A	N/A	-34	N/A	N/A	-27 (L)	N/A	N/A	-3 (L)

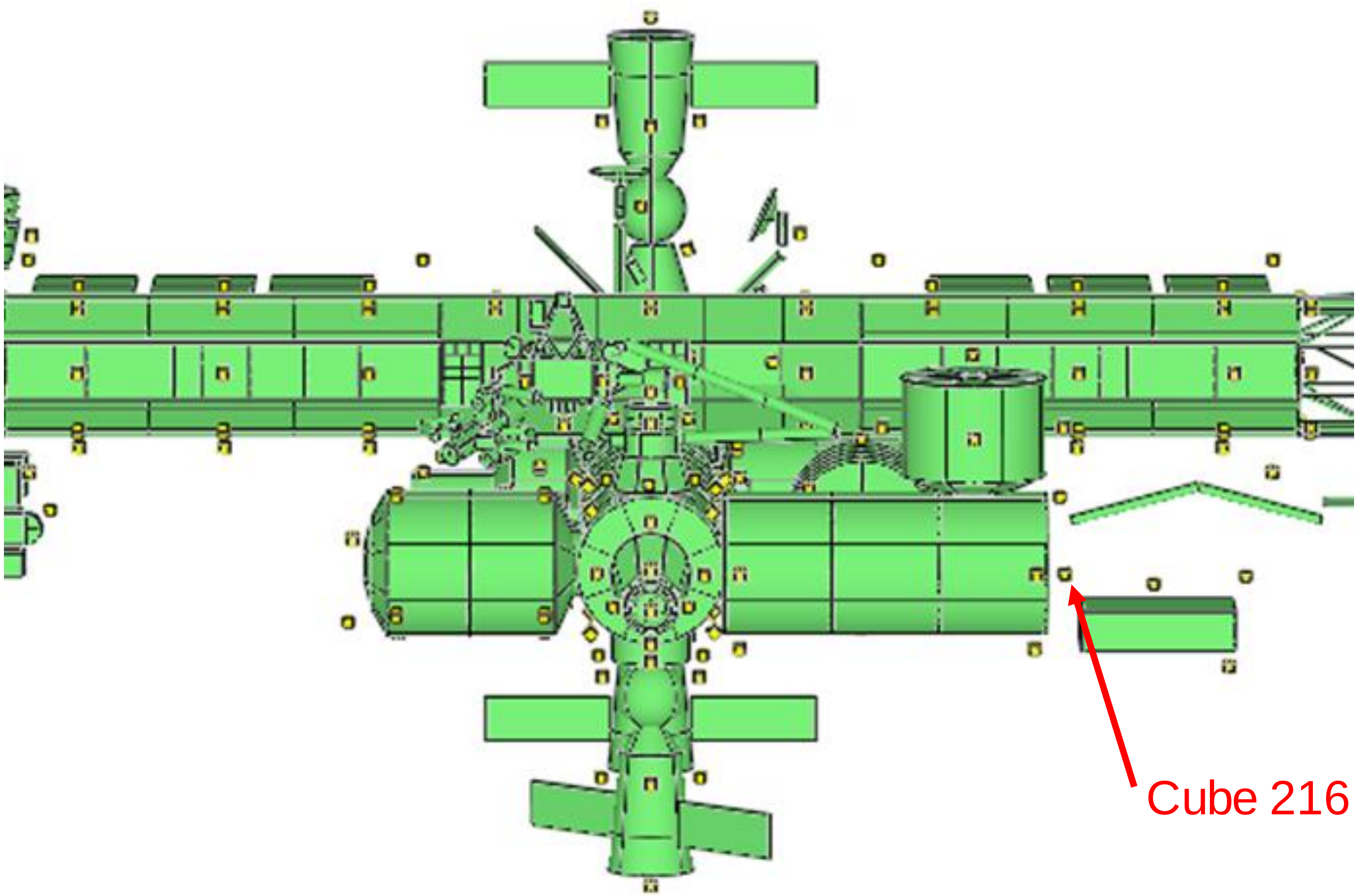
- For ratio 1, all environment temperatures are below slide table critical node limit with a 30 C environment change between solar beta +30° and 0°.
- The night pass temperature range is -47° C to -44° C with minimum value occurring at solar beta 0°.
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).

Cube 237 (Outboard) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	-28 (L)	N/A	N/A	-21 (L)	N/A	N/A	4 (L)
+60	-38 (L)	-20 (L)	-24	-38 (L)	-7 (L)	-14	-38 (L)	33 (L)	19
+45	-35	-11	-18	-35	7	-5	-35	57	36
+30	-36	-8	-17	-36	14	-1	-36	76	47
0	-37	-8	-18	-37	31 (U)	9	-37	118 (U)	79 (U)
-30	-31	-1 (U)	-11	-31	30	12 (U)	-31	107	74
-45	-29	-5	-12	-29	19	7	-29	83	61
-60	-27 (U)	-9	-14	-27 (U)	16	4	-27 (U)	79	56
-75	N/A	N/A	-7 (U)	N/A	N/A	7	N/A	N/A	52

- For ratio 1, all environment temperatures are below slide table critical node limit with a 30 C environment change between solar beta +30° and 0°.
- The night pass temperature range is -38° C to -27° C with minimum value occurring at solar beta +60°
- Optical Ratio 3 data has one violation of EVA incidental upper temperature (+112.8° C).

JEMAL Outer Hatch



Cube 216 (JEMAL Outer Hatch) Environment versus Solar Beta Angle for +XVV YPR = (-4°, -2°, +1°)

Solar Beta Angle	Optical Ratio 1 Sink Temp. (deg. C) (α/ε = 0.18/0.84 = 0.21)			Optical Ratio 2 Sink Temp. (deg. C) (α/ε = 0.66/0.74 = 0.89)			Optical Ratio 3 Sink Temp. (deg. C) (α/ε = 0.45/0.12 = 3.75)		
	Night	Day	Orbit	Night	Day	Orbit	Night	Day	Orbit
+75	N/A	N/A	0	N/A	N/A	28	N/A	N/A	101
+60	-47	7	-4	-47	42	26	-47	126	101
+45	-47	14 (U)	-2 (U)	-47	53	31 (U)	-47	146	111
+30	-46 (L)	13	-4	-46 (U)	57 (U)	31 (U)	-46 (U)	156 (U)	115 (U)
0	-63	-17	-31	-63	26	1	-63	118	77
-30	-65 (U)	-40	-48 (L)	-65 (L)	-28	-40 (L)	-65 (L)	8	-12
-45	-64	-42	-48 (L)	-64	-31	-40 (L)	-64	3	-13
-60	-63	-43 (U)	-48 (L)	-63	-33 (L)	-40 (L)	-63	-3 (L)	-15 (L)
-75	N/A	N/A	-41	N/A	N/A	-34	N/A	N/A	-11

- For ratio 1, all environment temperatures are below slide table critical node limit with a 30 C environment change between solar beta +30° and 0°.
- The night pass temperature range is -65° C to -46° C with minimum value occurring at solar beta -30°
- Optical Ratio 3 data has multiple violations of EVA incidental upper temperature (+112.8° C).